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Environmental and Energy Benefits of Microprocessor Control of Oven Airflows from Metal Painting Operations

Chemical Coaters Association, Wheaton, IL

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ENVIRONMENTAL AND ENERGY BENEFITS OF MICROPROCESSOR CONTROL OF OVEN AIRFLOWS FROM METAL PAINTING OPERATIONS

By

Chemical Coaters Association

CENTEC Corporation

Mack Trucks, Inc.

Cooperative Agreement No.
CR 8070833010

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16. ABSTRACT

In most industrial operations the percentage of the lower explosive limit (LEL) of VOC emissions typically remain at below 5 to 10 percent LEL at most metal coating operations. Although, monitors are available to determine solvent concentrations, they require manual corrective action to the process when potentially explosive oven atmospheres are generated. This project demonstrated the capability of microprocessors to control and allow ovens to operate close to 50 percent LEL while not exceeding that level. With instantaneous process control allowing operation closer to 50 percent of the LEL dilution air and energy requirements for the process and for incineration will be reduced. Successful demonstration of the use of microprocessors resulted in a control option that is both efficient and economical, and make the use of incineration with heat recovery much more efficient and attractive.

Included in this report is a technical design manual on the use and implementation of microprocessor technology into paint baking ovens for energy conservation and VOC pollution reduction from metal coating processes.

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This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on the environment and even on health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) and the Office of Industrial Programs, U.S. Department of Energy, Washington, D.C., assist in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report evaluates the use of microprocessor technology to enhance control of volatile organic compound emissions from paint curing ovens and simultaneously reduce the energy requirements and operating cost of the curing process. The program was cosponsored by the Chemical Coaters Association, the United States Department of Energy and the U.S. Environmental Protection Agency and has resulted in a fully demonstrated technology ready for immediate commercial application. Questions or comments regarding this report should be addressed to the Nonferrous Metals and Minerals Branch of the Industrial Environmental Research Laboratory in Cincinnati, Ohio.

David G. Stephan
Director
IERL-Ci

EXECUTIVE SUMMARY

Industrial coating curing ovens require ventilation air to maintain the solvent concentration below its lower explosive limit (LEL). However, higher than required ventilation air flow rates drastically increase the oven exhaust rate and result in higher energy and environmental compliance costs. The increased cost of environmental compliance results from larger incinerator capital and operating costs. The added energy costs are due to the heating requirements for the ventilation air and the added fuel for the incinerator.

Prior to this project, automatic control of ventilation air flow rates based on continuous solvent concentration measurements in curing ovens and microcomputer technology were not used in the American coating industry. There were several reasons for this:

- Only recently have fuel costs and environmental compliance requirements made improved control a major economic factor.
- There was considerable industrial skepticism about the accuracy of instruments for continuous measurement of solvent concentrations.
- The complexities of oven dynamics preclude simple analog control and it was only recently that the microprocessor brought digital control within an economic range for most oven systems.

Because of the large number of paint curing ovens in the United States, automatic control can have a major impact on the cost of environmental compliance and energy costs.

The U.S. Environmental Protection Agency, the Department of Energy, and the Chemical Coaters Association cooperatively sponsored a program to evaluate, design, and demonstrate automatic ventilation air flow rate control through direct measurement and control of the concentration of the solvent in the oven. The specific objective of this effort was to demonstrate that ventilation air flow rates could be safely reduced, thus reducing the energy costs for curing and incineration of solvents being vented from the curing oven.

There were four major tasks in the project:

- Evaluation of the potential value of the control technology
- Demonstration site selection and system design
- Installation and start-up of the prototype system
- Operation and evaluation of the prototype system

Prior to developing a control system, an industrial survey was undertaken to determine the potential benefits of this concept. A survey of 29 sites indicated that the average solvent concentration in the exhaust from curing ovens was about 7 percent of the LEL. In comparison, the National Fire Protection Association (NFPA) requires only that the percentage of the LEL be kept below 25 percent unless solvent indicators, alarms and shut-down of oven heating systems are provided. If this equipment is installed, the maximum solvent concentration should not exceed 50 percent of the LEL.

The lower than required solvent concentration in actual operation is usually a result of compounding safety factors built into the oven design, starting with the user's specifications and continuing with the oven manufacturer. The end result is excessively high curing oven ventilation air flow rates in most plants.

Based on the evaluation of curing oven systems during Task 1, it was concluded that automatic control could significantly reduce operating costs in both ovens and incinerators as well as lower investment costs for VOC control systems.

The sponsoring agencies stipulated that this concept be proven in the miscellaneous metal products industry and that its conclusions and benefits be applicable for other coaters using coatings containing volatile organic compounds. This could include such industries as:

- Coil
- Fabric
- Can
- Automobiles and Light Duty Trucks
- Printing
- Appliance

Based on established criteria for selection of a host site, Mack Trucks, Inc., agreed to participate. The Building 10 Assembly Plant in Allentown, Pennsylvania, which had multiple curing ovens and one catalytic incinerator, was chosen as the demonstration site. The curing ovens are typical of the systems used throughout the miscellaneous metal products coating industry.

Figure 1 shows the basic design functions of a control system. More complete information is given in the section, System Development and Demonstration. After a detailed evaluation, an Intel 8086-based controller and an analyzer using the flame ionization detection (FID) principle of operation were selected as the key hardware components. Solvent concentration was monitored at four points inside the controlled oven.

The system started up on October 1, 1981 and immediately reduced air flows from 1.6 m^3/s to 0.23 m^3/s (3400 $stdft^3/min$ to 490 $stdft^3/min$), a reduction of 86 percent. This resulted in an energy usage reduction for air heating of 55 percent in the curing oven and 13 percent in the catalytic incinerator. VOC destruction efficiency showed an improvement of 84 percent to 94 percent. At this point, most oven control dampers were closed and inflow from oven openings became the only source of ventilation air flow.

The control system at Mack Trucks was designed to control the dip oven at the minimum ventilation air flow rate which would either control the solvent concentration at 35 percent of the LEL or maintain a slightly negative pressure inside the oven. The control point became pressure; the maximum solvent concentration reached was 12 percent of the LEL. The minimum ventilation air flow rate was 0.23 m^3/s (490 $stdft^3/min$) which was 1.37 m^3/s (2910 $stdft^3/min$) lower than the rate before the control system was installed.

The expected control set point of 35 percent of the LEL was not reached for two reasons. First, due to the depressed truck market, the production level through the dip oven dropped to about one-third of the normal level which, in turn, reduced the solvent load. Secondly, although data received from Mack Trucks that represented normal production levels indicated that the solvent loading would give an average exhaust concentration of approximately 6 percent of the LEL at 1.6 m^3/s (3400 $stdft^3/min$) ventilation air flow rates, measurements taken at the plant just prior to installation of the control system showed that the solvent concentration was less than 1 percent of the LEL. With these very low solvent loadings and frequent line changeovers when no parts were cured, it was not possible to reach 35 percent of the LEL since the required air flow would be impractically low--well below normal in leakage. At an air flow

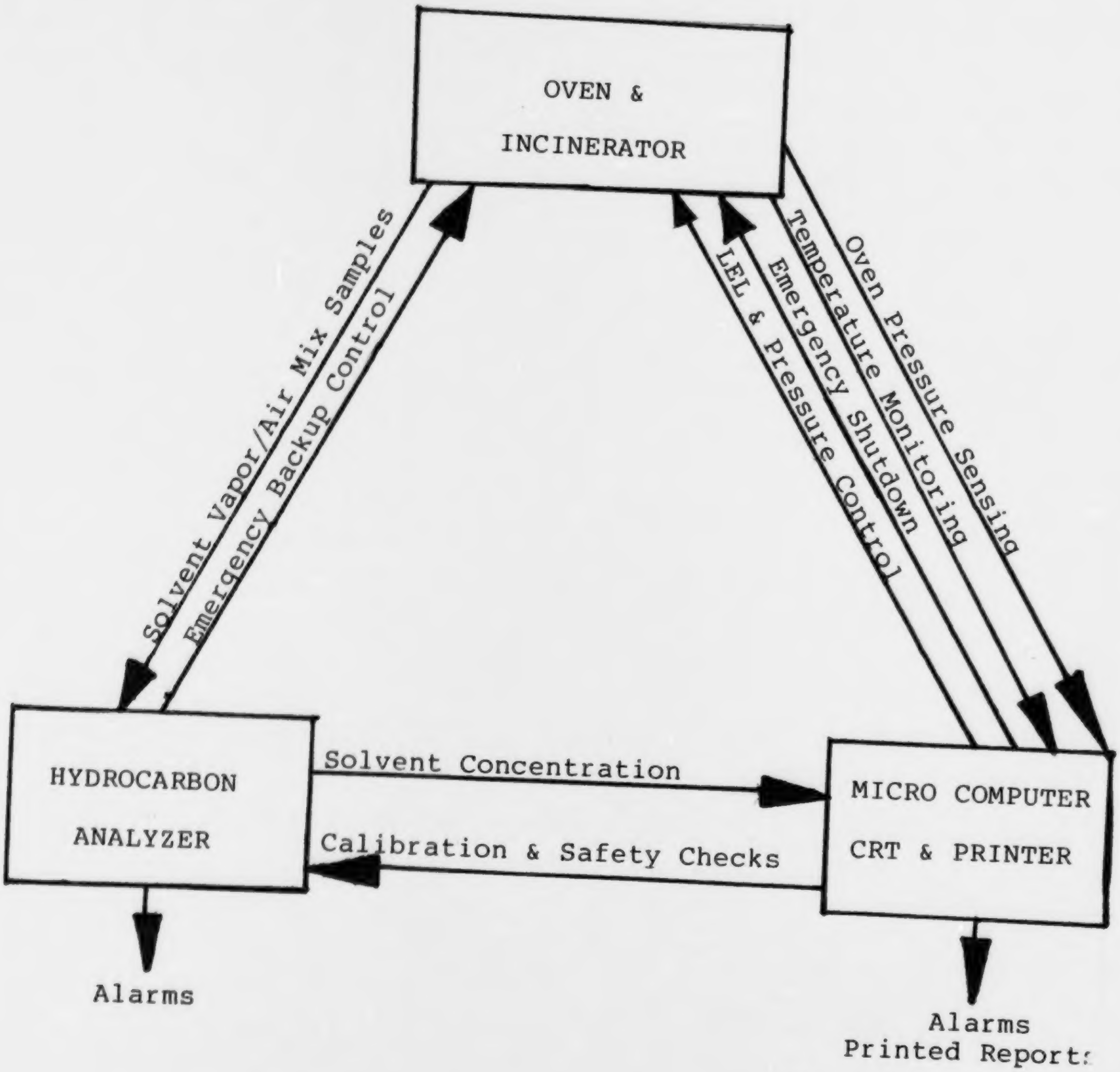
OVEN &
INCINERATOR
Solvent Vapor/Air Mix Samples
Emergency Backup Control
Temperature Monitoring
Oven Pressure Sensing
LEL & Pressure Control
Emergency Shutdown
HYDROCARBON
ANALYZER
Solvent Concentration
Calibration & Safety Checks
MICRO COMPUTER
CRT & PRINTER
Alarms
Alarms
Printed Report

Figure 1. Basic Design Features of Control System

rate of 0.23 m^3/s (490 $stdft^3/min$), the highest average solvent concentration approached 7 percent of the LEL. During brief runs at higher coating and production rates, the solvent concentration increased to 12 percent of the LEL.

Although the maximum solvent level of 35 percent of the LEL was not achieved, the primary objective of air flow reduction combined with proof of concept for all safety, operating control loops, and report generation was accomplished. The resulting energy savings in both the oven and incinerator were nearly equal to the projected savings. The air flow rate reduction was equal to the original projection of 1.3 m^3/s (2900 $stdft^3/min$).

Table 1 is a summary of oven conditions immediately before and after the system was placed in automatic control.

The system reliability appeared good, but decreasing production with numerous shutdowns because of low sales at Mack Trucks prevented long-term evaluation of continuous mechanical reliability. As expected, the only major systems requiring significant maintenance attention were the hydrocarbon analyzers.

With the first prototype testing complete, the expected benefits to other curing ovens can be calculated from a knowledge of oven flow rates and the average percent LEL maintained before control. Table 2 summarizes the projected industrial fuel benefits as a function of oven parameters for the various applications.

This project has shown that reduction of air flow in curing ovens via microprocessor control of solvent concentration is a practical, workable technology. Although the prove-out of the Mack Trucks parts line does not allow the automatic extension of the technology to ovens with higher and more variable solvent loadings and temperatures, it is felt that prove-out on these other applications will occur through normal commercial evolution.

TABLE 1. MACK TRUCKS' OVEN AND INCINERATOR CONDITIONS

	Before Automatic Control	After Automatic Control
Oven		
• Exhaust airflow, stdft^3/min	3400	490
• Solvent rate, lb/hr	5.7	5.7
• Exhaust solvent concentration, % LEL	1	7*
• Exhaust air temperature, °F	252	282
• Energy consumption, million Btu/hr	1.74	0.77
Incinerator†		
• Total airflow, stdft^3/min	9240	6330
• Operating temperature, °F	975	1014
• VOC destruction efficiency, %	84	94
• Energy consumption, million Btu/hr	4.7	4.1

* Maximum concentration in the oven was 12 percent of the LEL.

† Includes three ovens plus fume tunnel exhausts. Temperature increased due to minimum catalyst reactivity temperature requirement and the higher solvent concentration.

NOTE: Data supplied by Mack Trucks, October, 1981; incinerator fuel demands were variable due to cycling of the temperature controller.

TABLE 2. PROJECTED ENERGY BENEFITS FROM OVEN/INCINERATOR CONTROL FOR VARIOUS APPLICATIONS

	Miscellaneous Metal Products Coating	Fabric and Paper Coating	Coil Coating
Initial exhaust airflow rate, Stdft^3/min	2,000-10,000	10,000-17,000	17,000-40,000
Controlled exhaust airflow rate, Stdft^3/min	1,000-3,000	3,000-4,500	4,500-8,000
Solvent removal rate, gph	5-20	20-33	33-75
Energy consumption of oven wo/control, MM Btu/hr	1.0-4.0	4.0-6.5	6.5-15.0
Energy consumption of oven w/control, MM Btu/hr	0.5-1.5	1.5-2.0	2.0-3.2
Energy consumption of oven & incinerator wo/control, MM Btu/hr	3.0-15.0	15.0-25.0	25.0-60.0
Energy consumption of oven & incinerator w/control, MM Btu/hr	1.0-2.5	2.5-3.0	3.0-4.5

BASIS:

Solvent is Toluene
Initial solvent concentration is 7% of LEL
Oven exhaust temperature is 350°F
Thermal incinerator is operated at 1400°F, no heat recovery
Ranges below are approximations
Air heating demand only

* Final air flow rate reductions are dependent on solvent loadings, pressure control requirements and combustion air demand. Reference EPA report 450/2-77-008.

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ABBREVIATIONS

AIT - Analyzer Indicating Transmitter

BTU - British Thermal Units

CCA - Chemical Coaters Association

^{o}C - Degree Centigrade

DCF - Discounted Cash Flow

^{o}F - Degree Fahrenheit

FID - Flame Ionization Detector

FCV - Flow Control Value

I/P - Electrical to Pheumatic

LEL - Lower Explosive Limit

M^{3}/s - Cubic Meters Per Second

NFPA - National Fire Protection Association

P&I - Process and Instrument

PPM - Parts Per Million

$stdft^{3}/min$ - Standard Cubic Feet Per Minute

TII - Total Installed Investment

TT - Temperature Transmitter

VOC - Volatile Organic Compounds

W - Watts

CONVERSION FACTORS

To Convert From	To	Multiply By
Atmosphere (Atm)	Pascals (Pa)	1.013×10^5
Btu	Joules (J)	1.055×10^3
Btu/hr	Watt	.29307
Erg	Joules (J)	10^{-7}
Foot (ft)	Meter (m)	3.048×10^{-1}
Foot^3 (ft^3)	Meter^3 (m^3)	2.832×10^{-2}
Gallon/hr (gal)	Liter/hr	3.785
Inch (in)	Centimeter (cm)	2.540
Inch^2 (in^2)	Centimeter^2 (cm^2)	6.452
Kilogram force (kg)	Newtons (N)	9.807
Pound force (lb)	Newtons (N)	4.448
Pound mass (lb)	Kilogram mass (kg)	4.536×10^{-1}
Pounds per sq. in.	Pascals (Pa)	6.895×10^3
Standard Cubic Feet per hour	Cubic meters per hour	2.832×10^{-2}
Ton mass (short)	Kilograms mass (kg)	9.072×10^2

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CAUTION TO TECHNOLOGY USERS

The microprocessor control system demonstrated and described in this report was designed to conform with all insurance underwriters and NFPA paint bake oven design codes. In addition the generic system described herein takes into account NFPA codes to the extent that a general discussion of a generic system will allow; however, extreme caution must be exercised when designing a new paint bake oven or retrofitting an existing oven that utilizes this technology concept to ensure that the final oven design conforms with all applicable NFPA oven codes.

SECTION 1
INTRODUCTION

When organic solvent-based coatings are applied to metals in a manufacturing facility, the coated metal must pass through a curing stage. The application of heat in this stage removes the carrier solvent and "cures" the organic polymer coating by inducing further polymerization.

The enclosure in which this occurs is called a curing oven. The heat is normally supplied by natural gas burners operating directly in one of the oven air streams or through indirect heating using steam coils.

Since the flashed solvent is flammable (and under many conditions explosive), its concentration in the oven must be maintained well below the Lower Explosive Limit (LEL). This is accomplished by exhausting large volumes of ventilation air from the oven. Because the ventilation air must be heated to the curing temperature [93.33 to 427°C (200 to 800°F)], it represents a major energy requirement in the coating process.

In most cases, the oven ventilation air must be incinerated to meet required volatile organic compound (VOC) emission control requirements. Additional fuel is required to raise the temperature of the oven ventilation air sufficiently to incinerate the solvents. The fuel demand is directly proportional to ventilation air flow rate, solvent concentration, and final temperature necessary to assure satisfactory destruction efficiency.

Current insurance regulations allow operation of curing ovens up to 50 percent of the LEL if controls are operated to monitor and control solvent concentration and to shut down the oven automatically if 50 percent of the LEL is exceeded. Prior to this research project, however, no computer control system was commercially proven for these applications. Most plants set ventilation air rates at many times insurance requirements and are based upon precalculated values often far removed from actual oven operating conditions. In the past era of low natural gas prices and few requirements for incineration, this operating practice did not carry strong economic penalties.

The rise in natural gas prices, the requirements for further environmental control on VOC, and the appearance of lower cost microprocessor technology, however, all pointed to the need and feasibility of automatic control technology for curing ovens.* A key to successful automatic control is reliable LEL analyzers and an indepth understanding of oven dynamics. With automatic control, major savings in natural gas and operating cost of compliance with environmental regulations could be realized.

With the major benefits in mind, the U.S. Environmental Protection Agency, the Office of Industrial Programs of the Department of Energy, and the Chemical Coaters Association joined in a cooperative program to verify this technology in a manufacturing facility. This report describes the results of that program. The report consists of a Foreword, explaining the type of research and its general goals and purpose; an Executive Summary, summarizing the entire project; an Abstract, briefly describing the contents of the report; and the main body of the report covering an Introduction, Conclusions, Recommendations, and detailed technical description. Appendices include detailed background and supporting material.

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*There are over 13,000 curing ovens in the United States.

SECTION 2

CONCLUSIONS

REGULATIONS GOVERNING DESIGN OF CONTROL SYSTEMS

The National Fire Codes (Reference 1) published annually by the National Fire Protection Association (NFPA) were the basis for the process design and engineering of the microcomputer control system. Specifically the NFPA Code 86A provides the major safety requirements for monitoring and control of solvent concentrations and for setting ventilation air flow rates in continuous curing ovens. Three major requirements are noteworthy as stated in the Paragraph 4.2, Continuous Process Ovens, under Rate of Ventilation in order to comply with the code and to reduce ventilation air flow rates:

- "In continuous process ovens, the safety ventilation rate shall be designed and maintained to prevent the vapor con-concentration in the oven from exceeding 25 percent of the lower explosive limit.
- "The safety ventilation rate may be decreased when a continuous vapor concentration indicator and controller is provided. For such installations, the continuous vapor concentration indicator and controller shall be arranged to alarm and shutdown the oven heating systems or operate additional exhausters at a predetermined vapor concentration not to exceed 50 percent of the lower explosive limit.
- "... the recirculation and exhaust fans and other devices should be operated in such a manner that the vapor concentration is maintained at or less than the safe predetermined concentration."

SOLVENT CONCENTRATION IN EXHAUST FROM CONTINUOUS CURING OVENS

An evaluation of 60 continuous curing ovens indicated that the range of solvent concentrations in the ventilation air is in the range of 1 to 25 percent of the LEL. The average solvent concentration was found to be approximately 7 percent of the LEL. No data were available relating the concentration of the solvent inside the curing ovens to the exhaust gas concentration.

INVESTMENT COSTS FOR VOC EMISSION CONTROL

Discussions with incinerator suppliers and review of published cost data showed that the investment cost for incinerators increases directly with volumetric flow rate of air requiring control. Investment costs for heat recovery systems to reduce fuel demand for VOC emission control also increase directly with volumetric flow rates. The total installed investment for thermal incinerators is directly proportional to the total air flow rate. The investment cost is in the range of $5,000 to $22,000 per 0.47 m^3/s (1000 $stdft^3/min$) of air flow requiring control depending on the heat recovery options (Reference 2).

SAMPLING POINTS FOR MONITORING AND CONTROL

The NFPA Codes established guidelines for monitoring and or control of solvent concentrations. For multizone curing ovens when control systems are being evaluated, it was found to be necessary to have continuous sampling and measurement of the solvent concentration (percent of the LEL) inside the curing oven located at points where highest concentration of solvent can occur. At Mack Trucks, the exhaust solvent concentration was found to be 50 percent lower than the highest solvent concentration within the controlled curing oven. Therefore, control of the air flow by measuring only the concentration in the exhaust would lead to much higher concentrations inside the oven. As a result, control of the air should be implemented based on the highest solvent reading inside the curing oven.

MICROPROCESSOR APPLICABILITY

Microprocessor technology was proven to be applicable for automatic control and monitoring of air flow rates for conveyor curing ovens at Mack Trucks. Temperatures, solvent concentrations, pressures, and incinerator destruction efficiency could be obtained and displayed using a CRT.

PRODUCT QUALITY

Product quality was not affected by a reduction in ventilation air flow rate at Mack Trucks.

VENTILATION AIR FLOW REDUCTIONS

The ventilation air flow rate was reduced from 1.6 to 0.23 m^3/s (3400 to 490 $stdft^3/min$) under control. Further reductions were not achieved since this was the minimum air flow rate necessary to maintain a negative pressure at the entry and exit of the conveyor oven. This air flow rate reduction met the original projection of 1.37 m^3/s (2900 $stdft^3/min$).

MAXIMUM SOLVENT CONCENTRATION UNDER CONTROL

The original control set point for the Mack Trucks' installation was 35 percent of the LEL. The maximum solvent concentration reached during the project was 12 percent of the LEL inside the oven and 7 percent of the LEL in the exhaust. Lower production rates, about one-third of the normal level, and frequent product changeover (no coated parts being cured) combined to reduce the highest attainable solvent level. Since the air flow rate reduction was equal to the projection, the energy savings in the oven were equal to the original projection.

ENERGY SAVINGS FOR CURING AND INCINERATION

Calculations based on measured air flow rates and temperatures indicated a possible 55 percent reduction in total steam consumption for the curing oven and 13 percent reduction in fuel oil demand for the catalytic incinerator. The 55 percent reduction in total steam consumption translates into an 86 percent reduction in fuel demand for air heating in the curing oven. The energy demand to cure paint, heat the product, and for heat losses remains a constant. Only air heating demands are reduced with control. Measured fuel savings equaled the calculated oven fuel savings. The measured fuel savings for the incinerator were 12 percent lower than the calculated value because the incinerator temperature controller caused cycling of the incinerator temperature above and below a set point.

VOC DESTRUCTION EFFICIENCY

The VOC destruction efficiency was calculated continuously using the microprocessor. When the curing oven was controlled, the destruction efficiency improved by approximately 8 percent at Mack Trucks.

HYDROCARBON ANALYZERS

Many hydrocarbon analyzers are available for use by the coating industry. Based on the survey and literature review in this project, analyzers using the flame ionization detection principle were selected because of the response time, accuracy in terms of measuring percent of the LEL, and previous applications for monitoring solvent concentrations in the coating industry.

SAMPLE HANDLING FOR ANALYZERS

Condensation and sample line pluggage were prevented by the use of in-line filters and heated sample lines. The curing oven atmosphere contained particulates, resinous material, and solvents, which would have plugged or condensed in any lines that were not filtered and heated. Sample handling systems were needed for monitoring and control of solvent concentrations since plugging could have reduced response time for analyzer readings.

SECTION 3

RECOMMENDATIONS

This project successfully demonstrated a prototype microprocessor control system for use in continuous curing ovens in the miscellaneous metal fabricated parts industry. Further refinements of the technology can be accomplished by private industry to meet site-specific requirements of curing oven and incinerator operating conditions.

The following recommendations are made for further advancement of this technology in the coating industry:

- Investigate results of application for microprocessor control of curing ovens having high solvent loadings, e.g., coil coating and appliances.
- Investigate the need to establish as standard practice the continuous monitoring of destruction or capture efficiency for VOC emission control equipment in order to assure compliance with regulations and to optimize fuel and operating costs.
- Evaluate industrial practice on placement of the sampling point(s) to assure monitoring at locations where high concentration of solvents may develop.

SECTION 4

SYSTEM DEVELOPMENT AND DEMONSTRATION

As discussed in the INTRODUCTION and EXECUTIVE SUMMARY, the automatic control of ventilation air using microprocessor technology for curing ovens appeared to offer major fuel savings for curing ovens and for meeting compliance with environmental regulations. The fuel savings can be obtained by reducing the amount of air that must be heated in the curing oven and burned in a thermal or catalytic incinerator. The successful control of curing ovens requires the integration of a solvent concentration measurement system as well as a reliable process control system.

This section describes the curing operation, the project approach, and the basic theoretical background of the concepts. This section also contains a detailed discussion of the system design and the prototype test results.

CONTROL CONCEPTS AND PROJECT APPROACH

Critical Operation Parameters for Control

When coated metal enters a heated curing oven, the solvents in the applied coating begin to flash into the hot circulating oven air, which is heated either by direct combustion of natural gas or through heating coils. This gaseous stream contains combustion products from the direct fired heaters where applicable; the added ventilation air, which is used to maintain the solvent concentration in the oven below the LEL; and the VOC, which have flashed from the applied coating. The volume of air, combustion products, and solvents brought into the oven are vented by fans to the atmosphere or to VOC emission control equipment.

The organic components consist of numerous solvents with different vapor pressures and LEL's plus some of the monomer and low level polymers that may have sufficient vapor pressure at the oven curing temperatures to vaporize in significant quantities. This organic "mix" changes with the coating being applied, since there are hundreds of specially formulated coatings with proprietary solvent and monomer contents.

The measurement of the concentrations in the oven requires relatively sophisticated technology for the following reasons:

- The changing mixture of organics in the gas stream as product coatings change can modify the flammability characteristics of the oven gases.

- The rate and position in the oven of maximum evolution of solvent vapor is highly dependent upon vapor pressures and solvent content of the organic compounds of the coating being applied. Highly volatile solvents in high concentrations in the coating are emitted primarily in the early stages of the oven. Less volatile solvents reach peak evolution at later stages of the oven. If safe control is to be maintained, the sensors must detect these maximum levels and give an accurate reading of the percent of the LEL.

- The sample stream must be carefully conditioned and its compositional integration maintained until it is injected into the analytical instrument. This requires careful heating, filtering, and insulation of the sample line.

- The sample system must be designed to minimize plugging due to polymerization of the monomers and low level polymers.

In addition to evaporation of solvents, curing ovens are maintained under a slightly negative pressure at all times. As the temperature of the oven is changed, the volume of the air will either contract or expand. Air must be continually brought into the oven from the product entry and exit locations so that solvent laden fumes do not escape into the working environment. Therefore, the pressure of the oven must be below atmospheric as ventilation air flow rates and curing temperatures are changed. For these reasons, pressure sensors would be installed to provide signals to activate inlet and exhaust air dampers to maintain a negative pressure (vacuum) in the oven.

Therefore, the design of the control system itself hinged upon developing an understanding of the dynamics of the air flow rates and solvent concentration rates and a knowledge of the interaction between the solvent emission profile from the moving parts and the main air flow in the oven.

The required logic for the oven control algorithms was far too complex for an analog system, making the digital logic of a microprocessor an essential element of the control system.

In summary, a control system must:

- Maintain the proper pressure and solvent concentration throughout the curing oven and change the positions of all dampers to exhaust air at the points of the highest solvent concentration while keeping the oven under a negative pressure.

- Check continually for proper operation of components and respond in the event a fault is detected.
- Accommodate on-line changes in products and formulations, start-up, and line stoppages.
- Shut down the oven automatically in case of an unsafe condition.
- Require a minimum of operator attention.

Projected Results

The successful completion of this project was expected to clear the way for major savings in the installation and operation of environmental control equipment as well as providing savings in the oven operation itself. The savings for any specific oven, however, were found to be dependent upon several parameters that define the oven operating conditions. They include:

- Oven air flow rates
- Oven operating temperatures
- LEL levels that the oven is able to operate under without monitoring and control
- Configuration of the current VOC control system, if already installed
- Feasibility of heat recovery
- Oven design
- On-line operating time of the oven

A computer program, written in PASCAL for an APPLE II microcomputer, was used to evaluate the economic returns for an array of plant situations. The listing for this program is included in Appendix A of this report.

Based on the evaluation of current operating practices in the coating industry, it was found that most plants operate curing ovens with significantly more ventilation air flow than required for safety. The energy savings for control of the curing oven can be readily estimated based on existing air flow rate, exhaust air temperature, and solvent concentration (percent of the LEL). As shown in Figure 2, if a curing oven is being operated with a ventilation air flow rate of 4.72 m^3/s (10,000 $stdft^3/min$), an exhaust temperature of 177°C (350°F), the energy demand for air heating is 879 kW (3 million Btu/hr). The fuel demand at ventilation air flow rates beside 4.72 m^3/s (10,000 $stdft^3$) is calculated by taking the ratio of the actual ventilation air rate divided by 4.72 m^3/s (10,000 $stdft^3/min$) and multiplying the fuel demand obtained from Figure 2.

An approximation of fuel savings with control for any curing oven can be made quickly based on the existing total ventilation air flow rate m^3/s, exhaust temperature, and solvent concentration as percent of the LEL. The estimated savings would be calculated using the following formulas:

Formula 1: $AF_c = (AF_e \times C_e)/C_c$

AF_c - Air flow rate with control, scfm
AF_e - Existing air flow rate, scfm
C_e - Existing solvent concentration, percent of the LEL
C_c - Controlled solvent concentration, percent of the LEL

Formula 2: $FS = h(AF_e - AF_c)$

FS - Fuel saving, Joules/hr (W)
h - Enthalpy of air at oven exhaust temperature, Joules/m^3 (Btu/$stdft^3$)

The fuel savings calculated by Formula 2 can be adjusted to account for boiler efficiency (steam heated ovens) and the higher heating value of natural gas for direct fired ovens. Therefore, the savings in fuel demand are usually 15 percent higher when these factors are considered.

The fuel savings also can be calculated using Figure 2 with the following formula:

Formula 3: $FS = FE(\text{Figure 2}) \times (AF_e - AF_c)/AF_e$

FE - Fuel demand from Figure 2 adjusted for actual ventilation air flow rate, Joules/hr (million Btu/hr)

Basis

Exhaust Rate of 10,000 $stdft^3/min$
Fuel cost of $3.80/10^6$ Btu
4000 hrs per year operation
No heat recovery

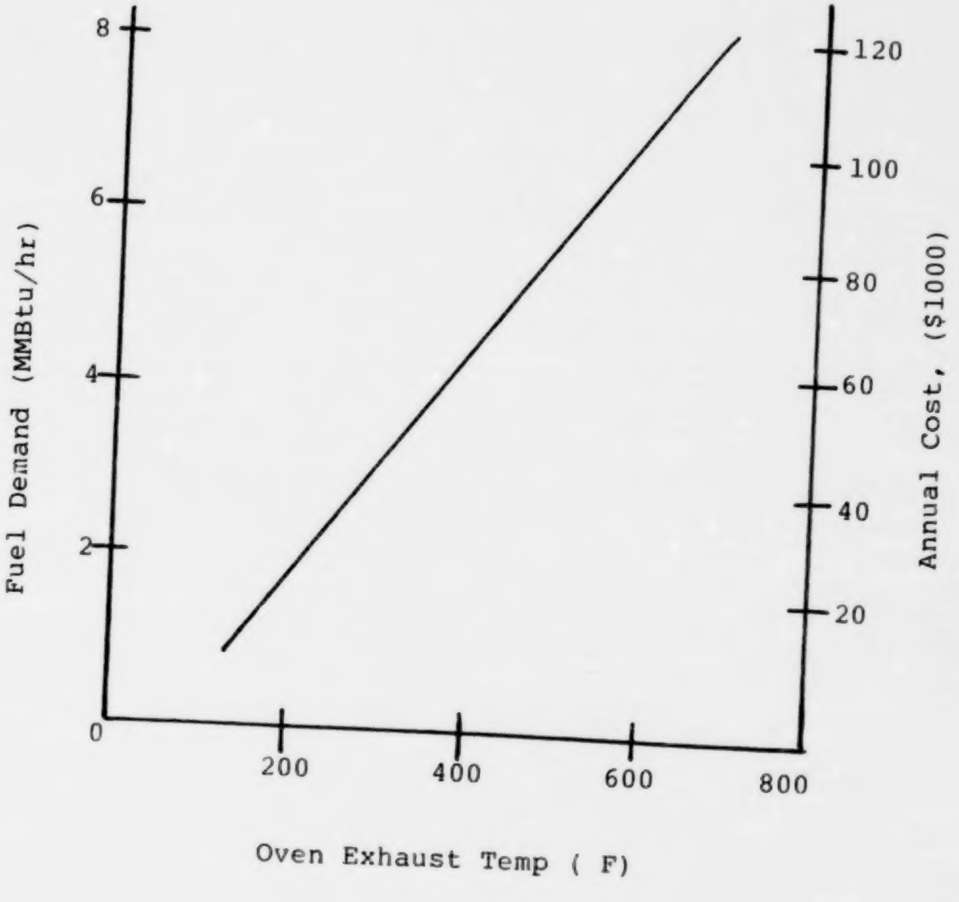

Figure 2. - Fuel Demand and Cost for Oven Air Heating

Similarly, the energy savings and capital costs for incineration can be reduced by installing a microprocessor control system. An example of the savings is shown in Table 3, which compares a non-controlled oven to a computer-controlled oven. If the non-controlled oven were to have a thermal incinerator added with 40 percent primary heat recovery, the total installed investment cost would be about $280,000 and the incinerator fuel demand would be 3,474 Joules/hr (3.7 million Btu/hr). With automatic control of the oven air flow rate, the plant could purchase a thermal incinerator without primary heat recovery at no energy penalty and with an investment cost of approximately $120,000. Methods for calculating fuel demand for incinerators are given in Reference 2.

Project Approach

This research project was initiated to identify and demonstrate the environmental and energy benefits of improved control of curing processes. A curing application in the miscellaneous metal products painting area was selected because these applications apply to the majority of the industry where variability of solvent loading and quality are major concerns and represent the most taxing operational environment for the computer controlled system.

On September 28, 1979 the Chemical Coaters Association signed a cooperative agreement with the Environmental Protection Agency for an evaluation and demonstration of the environmental and energy benefits achievable by microcomputer control of the ventilation air flow in curing ovens in the miscellaneous metal products industry. The Department of Energy's Office of Industrial Programs also supported the project by providing funds and technical assistance through an interagency agreement with EPA's Nonferrous Metals and Minerals Branch.

The Chemical Coaters Association established a technical committee for the purpose of monitoring the progress and reviewing the technical status of the project. The committee consisted of the project officers from the EPA and DOE and industrial members of the Chemical Coaters Association. CENTEC Corporation conducted the process and systems engineering work. Mack Trucks later became involved as the host site and provided engineering and site support to the project during the demonstration and evaluation of the prototype at their facility.

The goal was to develop a microcomputer control system for continuous curing ovens. The system was to automatically control solvent concentrations in curing ovens safely and without reducing operability of the ovens and was to reduce operating costs for curing ovens and emission control incinerators. The computer control system was to be designed to provide consistent

TABLE 3

ADVANTAGES OF CONTROL FOR COSTS OF INCINERATION

Operating Conditions	Non-Controlled Oven *	Controlled Oven †
Oven Exhaust Airflow Stdft^3/min	15,000	4,500
Oven Solvent Rate, lbs/hr	350	350
Oven Exhaust Air Temp., °F	600	600
Oven Fuel Demand, MM Btu/hr	9.0	3.0
Incinerator Fuel Demand, MM Btu/hr	3.7	0.2
Total Fuel Demand, MM Btu/hr	12.7	3.0
Total Fuel Savings, MM Btu/hr	---	9.5
Annual Fuel Savings, $	---	180,000
Incinerator Installed Investment Cost, $	280,000	120,000

BASES:

Fuel cost: $3.80/MM Btu
Incinerator Exhaust Temperature: 1,500°F
Annual Operation: 5,000 hours

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* Thermal incinerator with 40% primary heat recovery

† Thermal incinerator without heat recovery

optimum energy utilization for variations in both paint formulations and the products being coated. In addition to the primary function of ventilation air flow control, the control system was to continuously monitor and log operating conditions during normal production runs and was to produce reports automatically when problems affecting production or the control operation occurred.

The project consisted of the following four tasks:

- Task 1. Evaluate the potential value of the control technology. The detailed information on oven operating conditions across the targeted industry was to be obtained to confirm the initial evaluation that major savings in energy and pollution control costs were possible nationwide. In addition, the evaluation would point out the range of operating practices common in the industry, which would be invaluable in industry designs.

- Task 2. Complete conceptual system design and select site for prototype installation. Using the results from the survey in Task I, the major equipment and systems engineering components were to be individually evaluated for use with the microcomputer control system.

- Task 3. Develop final equipment specifications and purchase, install and operate a prototype system. The Mack Trucks' facility in Allentown, Pennsylvania was selected as the host site for the prototype demonstration.

- Task 4. Evaluate the results of the prototype operation.

SYSTEMS DESIGN

The prototype design resulted from a detailed industrial survey and oven design study combined with analyses using a computer program that calculated savings considering a range of oven operating conditions. In addition, because of the possibility of fires or explosions if there were component failures or flaws in the system logic, a detailed safety analysis was performed. Finally, numerous technical details related to placement of sample probes and control system logic were studied and resolved. This section discusses the major technical activities that led to the conceptual design and final design for the prototype installation.

Surveys

In order to ensure that the final system design would be applicable to a broad range of plants, an industrial survey was made of oven operating conditions.

A data form was submitted by the CCA to its members and non-member coating plants. This form was completed to ensure that enough information would be available for selection of a host site and for evaluation of process conditions for the design (See Appendix C). This data form requested information on coating formulations, coating application methods, solvent types and usage, and curing line operational details, including air flow rates, temperatures, production rates, fuel consumption, VOC emission control equipment, and plant potentials for waste heat recovery. The information was needed to characterize the industry, to accurately predict the energy and environmental benefits of air flow control, and to identify potential host site candidates.

Sixty data forms were distributed by CCA to companies in the miscellaneous metal products industry and to any other company wishing an evaluation. The project was described in the CCA Winter and Spring 1980 newsletters to its members and follow-up letters were sent to the plants that originally received the data forms. In addition, papers were presented by Mr. Matt Heuertz, Executive Director of the CCA, at the EPA/American Electroplaters' Society (AES) Third Conference on Advanced Pollution Control for the Metal Finishing Industry held April 14-16, 1980; at the CCA Eleventh Annual National Technical Seminar, Surface Coating '80 by Mr. Merle Kvaal, President (1980) of the CCA, held April 29-May 1, 1980; and at the Engineering Foundation Conference by Mr. Roy Radanof, CENTEC Corporation, held August 10-15, 1980. The objectives of these presentations were to solicit input for the project and to meet with representatives of companies that might be interested in participating as the host site. Also, a project brief was prepared and published in the May 1980 issue of Products Finishing magazine.

Twenty-nine data forms were received and evaluated by CCA from the initial distribution of 60 forms. Approximately 60 curing ovens were evaluated using the computer control model. Of the 29 plants, nine indicated a strong interest to be considered as a host site candidate after the evaluations were completed. Seven of these companies were in the miscellaneous metal products industry, the targeted industrial sector for a host site. The other two plants consisted of a coil coater and a fabric/paper coater.

To determine the applicability and design parameters for retrofitting ovens for microcomputer oven airflow control, a number of oven vendors were visited, including Schweitzer

Industrial Corporation, Midland-Ross Air System Division, Despatch Industries Incorporated, Michigan Oven Company, and Jensen, Incorporated.

Oven/Incinerator Computer Model

Accurate determination of energy usage and costs for the ovens, incinerators, and heat recovery options was achieved by using a computer analysis model developed to facilitate these calculations. The oven/incinerator design model determines the fuel consumption and fuel costs associated with continuous curing ovens and with incinerators used for volatile organic compound (VOC) air emission control. Fuel savings attributable to primary and secondary heat recovery schemes also can be computed.

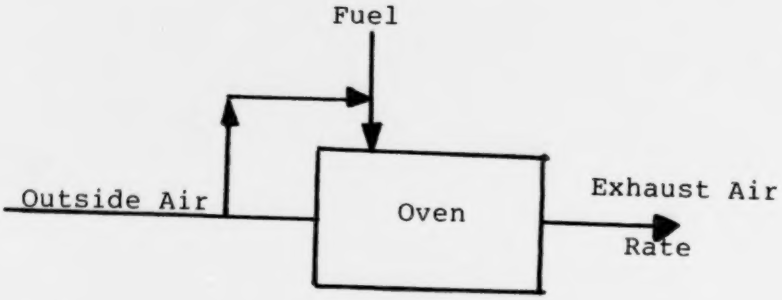
Energy costs can be determined using the model for the present operating conditions and for conditions representing automatic control of ventilation air flow rates. The model also can determine energy costs for incinerators and primary heat recovery. Figure 3 shows the various process layouts that are quickly analyzed using the model. Examples of the model printout reports and the model software are included in Appendix C.

The model has a built-in file on solvents and their properties so that all calculations are based on actual constituents rather than average values. Solvent destruction efficiency is factored into fuel flow computations for incinerators. The costs for incinerating air from spray booths and multiple ovens entering the same control device also can be computed by the model. The energy demand for catalytic and thermal incinerators can be determined while considering internal and external combustion air sources and different fuel types.

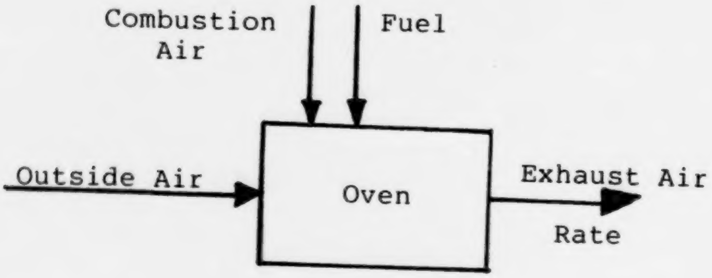
Therefore, the model could provide accurate results based on the following data from a plant:

- Exhaust ventilation air temperature
- Ventilation air flow rate
- Solvent concentration as percent of the LEL in the exhaust or solvent rate being evaporated, gal/h
- Estimate of solvent composition
- Fuel type and costs and general operating hours
- Schematic of system
- Operating temperatures for VOC emission control equipment

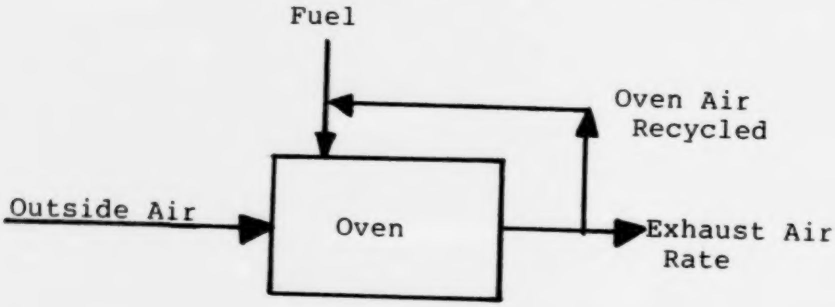
Three Oven Configurations


Fuel
Outside Air
Oven
Exhaust Air
Rate

1. Oven with Internal Combustion Air For Burners


Combustion
Air
Fuel
Outside Air
Oven
Exhaust Air
Rate

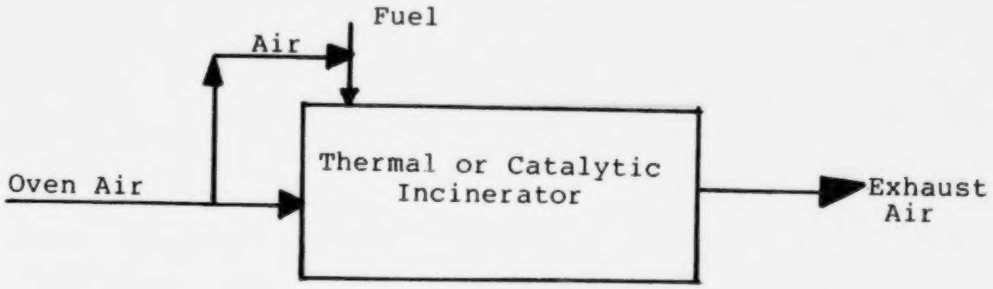
2. Oven with External Combustion Air For Burners


Fuel
Oven Air
Recycled
Outside Air
Oven
Exhaust Air
Rate

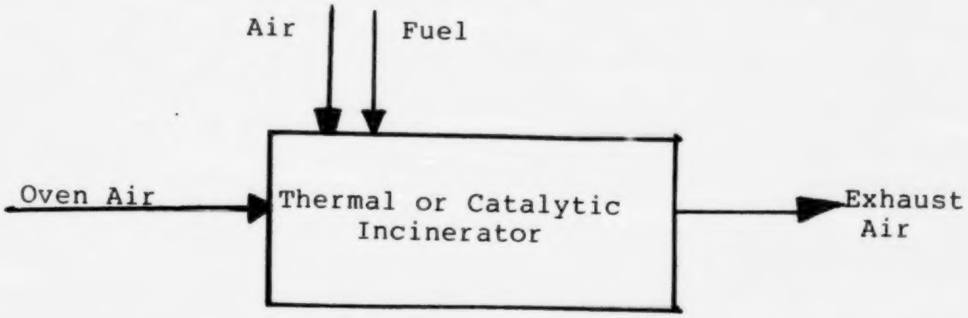
3. Oven with Zone Type Burners

Figure 3. Possible Configurations To Be Used With Oven/Incinerator Model

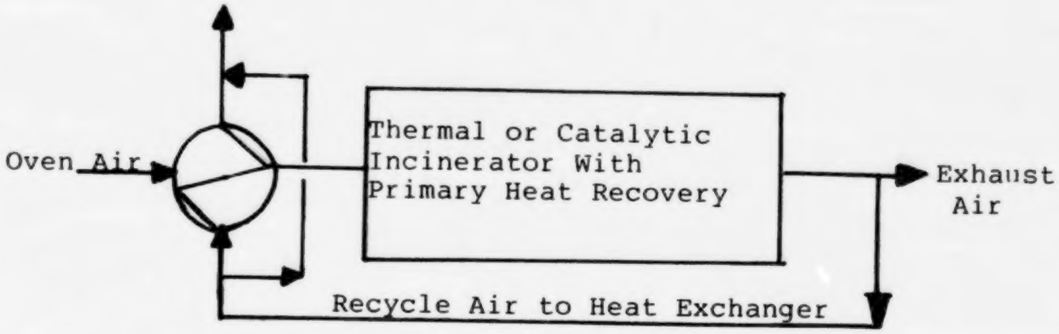
Three Incinerator Configurations


Fuel
Air
Oven Air
Thermal or Catalytic Incinerator
Exhaust Air

1. Internal Combustion Air For Incinerator Burner


Air
Fuel
Oven Air
Thermal or Catalytic Incinerator
Exhaust Air

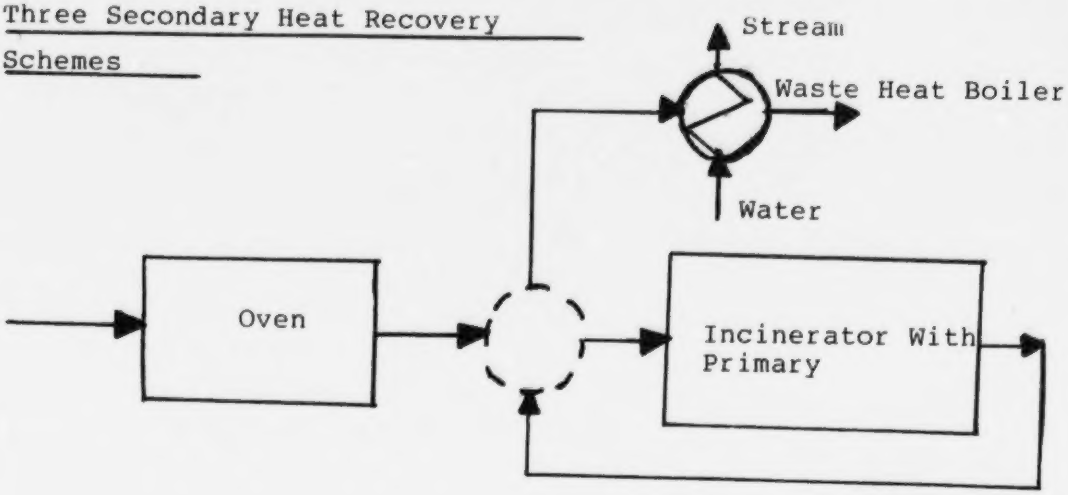
2. External Combustion Air For Incineraotr Burner


Oven Air
Thermal or Catalytic Incinerator With Primary Heat Recovery
Exhaust Air
Recycle Air to Heat Exchanger

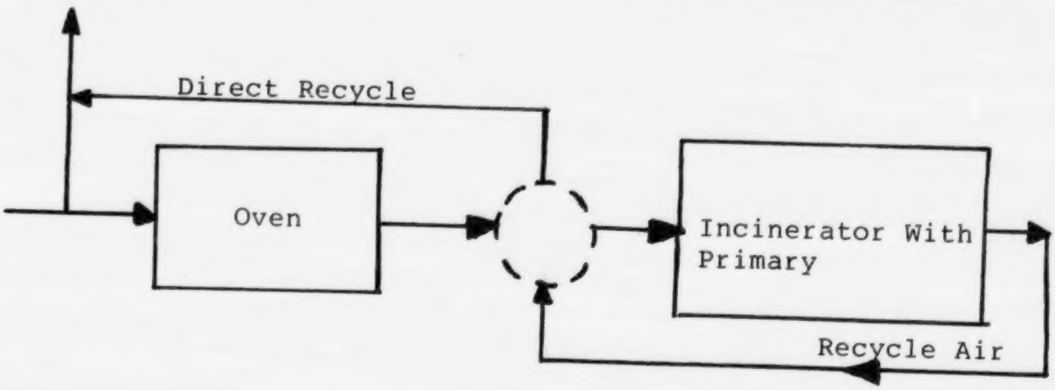
3. Primary Heat Recovery

Figure 3. Cont'd

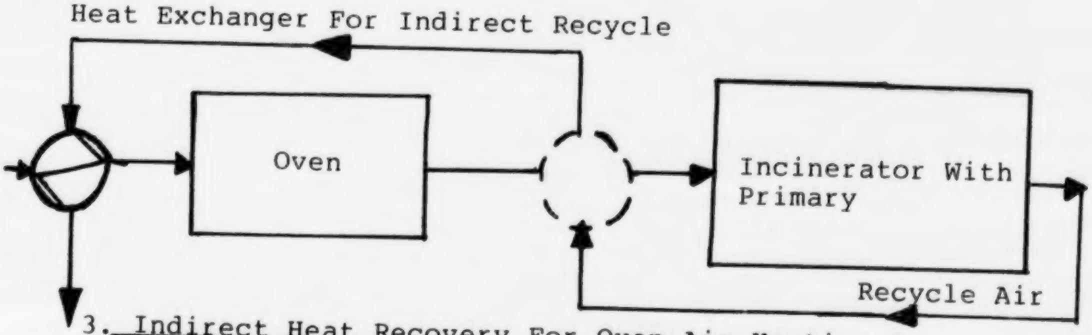
Three Secondary Heat Recovery Schemes


Stream
Waste Heat Boiler
Water
Oven
Incinerator With Primary

1. Waste Heat Boiler For Secondary Heat Recovery


Direct Recycle
Oven
Incinerator With Primary
Recycle Air

2. Direct Recycle To Oven For Secondary Heat Recovery


Heat Exchanger For Indirect Recycle
Oven
Incinerator With Primary
Recycle Air

3. Indirect Heat Recovery For Oven Air Heating As Secondary Heat Recovery

Figure 3. Cont'd

The fuel costs determined by the computer model were used as input to an existing economics model for determining discounted cash flow rates of return, returns on investments, and paybacks for capital investments. The capital investment was based on estimated total installed costs for microcomputer control systems and for heat recovery and VOC emission control equipment.

The results of the model runs were tabulated and sent to the prospective candidate host sites for their evaluations. Each company was contacted for further discussions pertaining to their commitment for becoming a host site for the prototype.

Safety Analysis

A formal safety analysis had to be completed in order to develop the safety design criteria for the systems engineering work. Also, the safety analysis was performed in order to determine what would be the effects of greatly reduced ventilation air flow rates on the overall safety of the operation. The NFPA Codes already permit operation up to 50 percent of the LEL, provided certain conditions are met; however, it became a necessity to assess what factors could contribute to unsafe conditions and how the controller could compensate and prevent these conditions from occurring. Initially, the type of safety analysis had to be selected and then the factors contributing to unsafe conditions and actions to prevent explosions had to be listed before the safety analysis could begin.

The safety analysis of the curing oven system had to include a systematic examination of the possibility of exposure of personnel and property to unsafe conditions. This investigation, therefore, considered both theoretical and practical possibilities. Three formalized methods exist for systematically evaluating a process for potential hazards: the What-If method, the Fault Tree Analysis, and the Failure Mode and Effect Analysis (References 3 to 8).

The What-If method is based on the compilation of "What If" questions about each important process function. Each potential problem from process component failure or procedural error on the process must be identified along with the detection method and corrective action for each problem.

A Fault Tree Analysis is a systematic technique that originated for use in the aerospace industry. A schematic of the primary potentially hazardous initial, intervening, and final events had to be developed including any event that could result in an undesired event, such as a flame-propagating explosion.

The objective of the analysis was to determine how the process equipment, its operation, and errors by operating personnel could cause the undesired event. This method is single-event oriented; the event to be studied is generally established as a result of a hazard review utilizing the What-If method.

The Failure Mode and Effect analysis deals primarily with equipment failures. Each component of the system is assigned a hazard rating and a probability-of-failure factor; the product of these two values results in the relative degree of risk involved if a component fails. The major drawback of this method is its inability to identify sequences of events that may not be a problem individually but which collectively could result in the undesirable event. This method was not used for this analysis because the possibility of developing unsafe operation in curing ovens was believed to result from a sequence of events and lack of process response to those occurrences.

Therefore, the safety analysis was completed using the Fault Tree Analysis since it incorporated the findings of the What-If method. The What-If method was used to identify specific problems and actions required for implementing design. The Fault Tree Analysis was used to compare the degree of safety between controlled ovens and ovens without control with explosion being the major event to be prevented.

The What-If questions were formulated based on the NFPA Codes, and consultation with the project team and oven vendors. The compilation of the problems, detection method, and actions required to assure safety are shown in Table 4. The possible problems with a microcomputer control system, its auxiliary components, such as analyzers, and existing plant utility services were identified along with detection methods and required actions.

Based on the What-If method of anlaysis, the microcomputer control system design could be developed to safely handle all of the potentially hazardous conditions and equipment failures.

The schematic developed for the Fault Tree Analysis is shown in Figure 4. An oven explosion is the major event to be prevented. The two major causes of that occurrence are VOC levels exceeding 50 percent of the LEL and/or oven fuel safety failure, such as the lack of automatic shut-off. Figure 5 provides the legend for the symbols shown in Figure 4.

The failure sequences can be identified from the fault tree, Figure 4, by utilizing the subevent number or letter designations and the logic probability arithmetic. From these failure sequences, the critical path is determined by visual inspection of the fault tree.

TABLE 4. "WHAT IF" ANALYSIS

	PROBLEM	DETECTION METHOD	ACTION REQUIRED
	WHAT IF............		
1.	#1 LEL analyzer sample line plugs?	Low sample flow activates low flow switch.	Microcomputer signals oven exhaust damper to full open and activates alarm.
2.	#2 LEL analyzer sample line plugs?	Low sample flow activates low flow switch.	Microcomputer signals oven exhaust damper to full open and activates alarm.
3.	#1 LEL analyzer low flow switch fails to indicate low flow?	#1 LEL analyzer output will differ from #2 LEL analyzer output when compared by the microcomputer.	Microcomputer signals oven exhaust damper to full open and activates alarm.
4.	#2 LEL analyzer low flow switch fails to indicate low flow?	#2 LEL analyzer output will differ from #1 LEL analyzer output when compared by the microcomputer.	Microcomputer signals oven exhaust damper to full open and activates alarm.
5.	#1 LEL analyzer calibration gas pressure is low?	#1 LEL analyzer low pressure switch is activated.	Microcomputer signals oven exhaust damper to full open and activates alarm.
6.	#2 LEL analyzer calibration gas pressure is low?	#2 LEL analyzer low pressure switch is activated.	Microcomputer signals oven exhaust damper to full open and activates alarm.
7.	#1 LEL analyzer calibration gas low pressure switch fails to operate?	Microcomputer "knows" what value the analyzer should be reading when the analyzer is in the calibration mode and will compare the output of the analyzer to the value in the microcomputer's memory.	Microcomputer signals oven exhaust damper to full open and activates alarm.

TABLE 4. "WHAT IF" ANALYSIS
(Continued)

	PROBLEM	DETECTION METHOD	ACTION REQUIRED
8.	#2 LEL analyzer calibration gas low pressure switch fails to operate?	Microcomputer "knows" what value the analyzer should be reading when the analyzer is in the calibration mode and will compare the output of the analyzer to the value in the microcomputer's memory.	Microcomputer signals oven exhaust damper to full open and activates alarm.
9.	#1 LEL analyzer sample line electrical heat tracing fails?	Quantity of sample may be reduced due to condensing of the VOC component which will cause the #1 LEL analyzer output to differ from the output of the #2 LEL analyzer when compared by the microcomputer.	Microcomputer signals oven exhaust damper to full open and activates alarm.
10.	#2 LEL analyzer sample line electrical heat tracing fails?	Quantity of sample may be reduced due to condensing of the VOC component which will cause the #2 LEL analyzer output to differ from the output of the #1 LEL analyzer when compared by the microcomputer.	Microcomputer signals oven exhaust damper to full open and activates alarm.
11.	The LEL level exceeds the limit set point on either analyzer?	Analyzer output would be higher than set point.	Analyzer activates high LEL level alarm, and microcomputer signals oven exhaust damper to full open. If level continues to increase, then the product conveyor and coating application would be stopped.
12.	The process instrument air pressure is low?	Low instrument air pressure activates a low pressure switch.	Damper activators have built-in safety feature which causes them to fully open on low instrument air pressure.

TABLE 4. "WHAT IF" ANALYSIS
(Continued)

	PROBLEM	DETECTION METHOD	ACTION REQUIRED
13.	The process instrument air pressure drops below normal and the low pressure switch fails to operate?	Limit switches on dampers will indicate a change in positioning.	All dampers in oven system will fail open causing limit switches to indicate fully open dampers.
14.	A power outage occurs?	Total system is down.	All dampers would fully open, the product conveyor would stop and the oven and incinerator fuel valves would fail closed.
15.	The oven exhaust damper fails to go full open for items 1 through 10 above?	Limit switch on damper assembly is not activated within a predetermined time interval which activates an alarm.	Operator must manually open damper to full open. If the solvent concentration should exceed the analyzers' set point before the damper is fully opened, then the microcomputer will stop the product conveyor and the coating application.
16.	The oven fuel control valve fails to close on demand?	Limit switches doe not indicate a closed valve and oven temperature would increase.	High temperature cut-off will activate existing safety valve in oven fuel system (as per NFPA 86 A).
17.	The VOC destruction efficiency falls below the desired level?	Microcomputer computes destruction efficiency based on solvent concentration detected by analyzers at the exit of the oven and at the exit of the incinerator and compares the computed value to the desired level.	Temperature control on incinerator would be manually adjusted.
18.	A coating and/or product line changeover occurs?	LEL analyzers would sense a change in the measured solvent concentration.	Microcomputer would adjust dampers to bring solvent concentration back to set point.

TABLE 4. "WHAT IF" ANALYSIS
(Continued)

PROBLEM	DETECTION METHOD	ACTION REQUIRED
19. The primary heat recovery unit begins to plug?	Differential pressure and temperature sensors located in the inlet and outlet ducting will indicate values out of the normal operating range as monitored by the microcomputer.	Microcomputer will activate alarm to manually shut the system down. If a high LEL is detected by the analyzers before the operator manually shuts the system down, the analyzers will automatically deactivate the product conveyor and close the fuel valve.
20. A temperature or pressure sensor in the primary heat recovery inlet and/or outlet ducting malfunctions?	Microcomputer monitor system will detect malfunctioning unit. Since a sensor is located in each of the inlet/outlet ducts, a certain degree of redundancy is provided to double check monitoring integrity.	Microcomputer will activate alarm of a malfunctioning unit.
21. The exhaust blower fails?	Existing NFPA 86A requirements specify that an electrical interlock be provided between the exhaust blower and the oven fuel. Also, an out of range pressure reading and a high LEL in the oven would be sensed by the microcomputer.	The electrical interlock will shut-off the fuel valve and the conveyor system. If the interlock should fail, the microcomputer and analyzer system will act as back-up to shutting off the conveyor and closing the fuel valve.
22. An operator over charges solvent to oven?	LEL analyzer will detect increasing solvent concentration.	As solvent increases, dampers will be opened. If LEL set point is exceeded then microcomputer will completely shut system down and alarm.

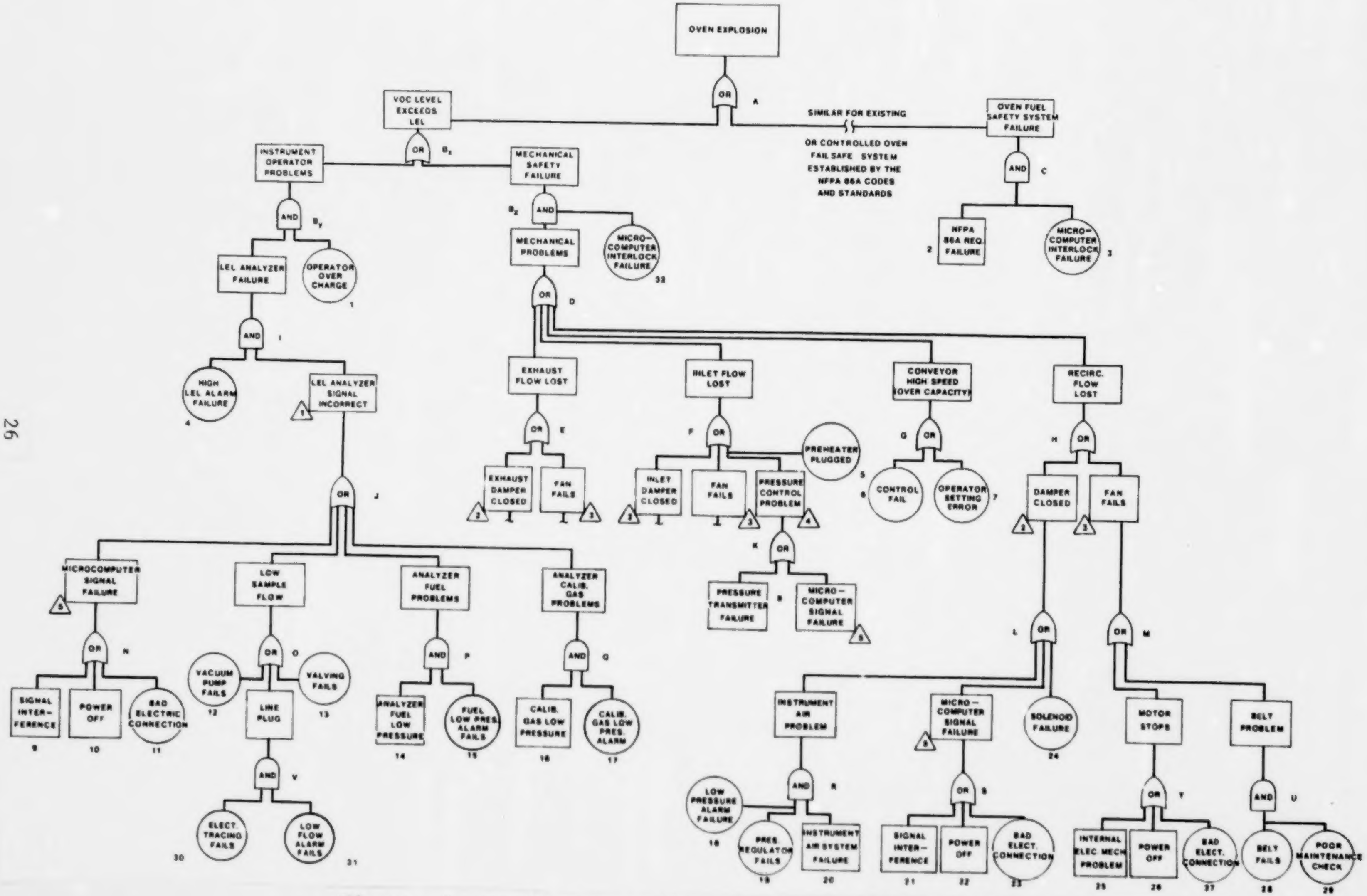
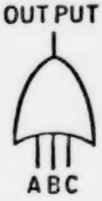

OVEN EXPLOSION
OR
A
VOC LEVEL EXCEEDS LEL
OR
B_x
SIMILAR FOR EXISTING
OR CONTROLLED OVEN FAIL SAFE SYSTEM ESTABLISHED BY THE NFPA 86A CODES AND STANDARDS
OVEN FUEL SAFETY SYSTEM FAILURE
AND
C
NFPA 86A REQ. FAILURE
2
MICRO-COMPUTER INTERLOCK FAILURE
3
INSTRUMENT OPERATOR PROBLEMS
AND
B_y
LEL ANALYZER FAILURE
OPERATOR OVER CHARGE
1
AND
I
HIGH LEL ALARM FAILURE
4
LEL ANALYZER SIGNAL INCORRECT
1
OR
J
MECHANICAL SAFETY FAILURE
B_z
AND
MECHANICAL PROBLEMS
MICRO-COMPUTER INTERLOCK FAILURE
32
OR
D
EXHAUST FLOW LOST
OR
E
EXHAUST DAMPER CLOSED
2
FAN FAILS
3
INLET FLOW LOST
F
OR
INLET DAMPER CLOSED
2
FAN FAILS
3
PRESSURE CONTROL PROBLEM
4
PREHEATER PLUGGED
5
K
OR
PRESSURE TRANSMITTER FAILURE
8
MICRO-COMPUTER SIGNAL FAILURE
5
CONVEYOR HIGH SPEED (OVER CAPACITY)
G
OR
CONTROL FAIL
6
OPERATOR SETTING ERROR
7
RECIRC. FLOW LOST
H
OR
DAMPER CLOSED
2
FAN FAILS
3
L
OR
M
OR
MICROCOMPUTER SIGNAL FAILURE
5
OR
N
SIGNAL INTER-FERENCE
9
POWER OFF
10
BAD ELECTRIC CONNECTION
11
LOW SAMPLE FLOW
OR
O
VACUUM PUMP FAILS
12
VALVING FAILS
13
LINE PLUG
AND
V
ELECT. TRACING FAILS
30
LOW FLOW ALARM FAILS
31
ANALYZER FUEL PROBLEMS
AND
P
ANALYZER FUEL LOW PRESSURE
14
FUEL LOW PRES. ALARM FAILS
15
ANALYZER CALIB. GAS PROBLEMS
AND
Q
CALIB. GAS LOW PRESSURE
16
CALIB. GAS LOW PRES. ALARM
17
INSTRUMENT AIR PROBLEM
AND
R
LOW PRESSURE ALARM FAILURE
18
PRES. REGULATOR FAILS
19
INSTRUMENT AIR SYSTEM FAILURE
20
MICRO-COMPUTER SIGNAL FAILURE
5
OR
S
SIGNAL INTER-FERENCE
21
POWER OFF
22
BAD ELECT. CONNECTION
23
SOLENOID FAILURE
24
MOTOR STOPS
OR
T
INTERNAL ELEC. MECH PROBLEM
25
POWER OFF
26
BAD ELECT. CONNECTION
27
BELT PROBLEM
AND
U
BELT FAILS
28
POOR MAINTENANCE CHECK
29

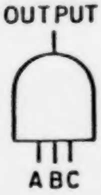
Figure 4. Fault Tree--Microcomputer Controlled/Existing Curing Ovens

SYMBOLS



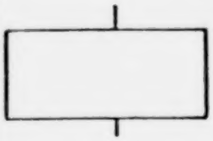
"OR" Gate

This gate is in the failed state if at least one of its inputs is in the failed state.
Probability of Output = Probability of A + B + C



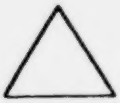
"AND" Gate

This gate is in the failed state only if all its inputs are simultaneously in their failed states.
Probability of Output = Probability of A x B x C



Subevent

The rectangle describes the event which is the output of a logic gate.



Transfer

The triangle transfers an entire part of the tree to another location on the tree or to another page of a subdivided tree.

Figure 5. Symbols For Fault Tree Analysis (Figure 4)

The critical failure paths were developed for the controlled oven and the standard uncontrolled oven. The component failure rates were incorporated into the critical path, and the probability of the undesired event occurring were calculated. Refer to Appendix D for results of analysis. From the Fault Analysis, the probability of an undesirable event resulting from excessive LEL was found to be one incident in 7.4 days without control. This is much higher than would be expected because the failure rates utilized are based on chemical-plant failure data that has more severe operational and environmental conditions than a curing plant. Since failure rate data did not exist for the coating industry, the chemical industry data was used because of the similarity of processing hydrocarbons. The analysis found that the controlled oven probability of explosion utilizing microcomputer technology was one incident in 672 years. Appendix D gives the calculations for this conclusion. Therefore, comparison of the controlled oven and the standard oven probabilities of explosion indicated that the controlled oven should be many magnitudes safer than are uncontrolled ovens.

SYSTEM SOFTWARE AND OPERATING LOGIC DEVELOPMENT

Conceptual Design Basis

The selection of microcomputer system components and programming language upon which to base the oven control system required an analysis of the software and hardware offered by microcomputer manufacturers. The programming languages had to be powerful enough to handle all of the control logic. Also, the hardware selection criteria specified selection of microcomputers with a history of reliable service and compatibility with software. The hardware for the microcomputer had to be selected so that the same equipment could be used off-site for the development work and could be installed for control of the oven at the plant site.

To guide in the development of a feasible and cost-effective microcomputer-based control system for curing oven systems in the targeted industry, the following basic design goals and strategies evolved based on safety analyses and system requirement studies: The hardware and software, which make up the microcomputer-based controller, had to be capable of performing the following functions:

- Have control features to take sensor readings of solvent concentrations and pressures in curing ovens and provide control signals for varying air flow rates

- Provide consistent performance and quick response for variations in solvent rates and pressures within the curing ovens

- Comply with the codes and standards of the National Fire Protection Association

- Have good reliability and availability of parts

- Provide capability to interface with other host computers

Consistent with the functions set forth, the following five major design activities evolved for selection of hardware and software for the microcomputer. These activities involved the approach to systematic development of software as well as the site requirements for operation in the coating industry.

- Adherence to Principles of Structured Analysis and Design: Software design and implementation would be conducted according to structured design and analysis which was first promulgated by Edsger Dijkstra. This approach places an emphasis on the hierarchical nature of system functions for the application, the necessity for well defined inputs from sensors, and outputs for control and monitoring functions. The control logic first had to address safety requirements and optimization of the curing oven and had to address data collection for reports secondly.

- Process Interface Hardware Requirements: The prototype microcomputer-based controller would need to be configured to provide the basic control and safety functions for the oven/incinerator/heat recovery system requirements. Due to the unknowns encountered in research and development, the software and hardware had to be flexible enough to be updated at the site. The dynamics of the curing oven could not be simulated in the laboratory so on-site modifications to software would become a requirement for selection of components.

- Operator Interface: The application and design of the software had to provide operators with visual aids to assess operating status for the system and to change from manual to automatic control. The operator control selection would be developed to be consistent with the current operating procedures. A knowledge of computer programming would not be available on-site after initial start-up; therefore, simple keyboard commands and a color CRT for visual display of operating conditions and control status had to be incorporated.

- Report Generation: Keeping well organized, easily accessible, and complete records on system operating conditions would be required as part of the operation for the control system. As a minimum, reports had to be automatically generated when alarm conditions occurred to provide a permanent record of the process conditions in the oven at that time. Also, it was concluded that the software had to allow generation of a report on command or at time intervals specified by the company incorporating a control system. The time allotted to the report generation and displays could not interfere with the primary function of control and safety.

- System Reliability, Maintenance and Back-up: All computer system components would be proven, commercially available parts incorporating the latest Large-Scale Integration (LSI) technology and solid-state circuitry. These microcomputer components would have to be configured for the oven control application. No custom designed application-unique hardware would be incorporated into the prototype system. Therefore, site location, accessibility to hardware service centers, vendor maintenance personnel, and spare parts stockage policies would be considered as additional factors for final selection of critical system components.

Given the microcomputer software and hardware selection criteria, the major auxiliary equipment necessary for implementation of automatic control was identified for meeting the requirements of the safety analyses and NFPA Codes. Although the number of sensor input and control outputs would depend on the requirements of the site, the following elements for control were incorporated into software to cover most curing oven applications.

- Hydrocarbon Analyzers: The analyzers would be installed to measure continuously the solvent concentration in the curing oven and exhaust ductwork. These readings would become inputs to the microcomputer. The outputs from the microcomputer would adjust the exhaust damper(s) based on the highest readings of percent of the LEL. Any solvent measurement in the oven or exhaust ductwork would become a control point. Other points for monitoring destruction efficiency of incinerators would be included for optimization of the system or for operating displays. The microcomputer would provide the means for controlling solvent concentration not to exceed 50 percent of the LEL at any point in the oven. Software would be developed to prevent any chance of the plant setting the control point above 50 percent of the LEL.

- Pressure Sensors: Pressure sensor readings would become inputs to the microcomputer. The outputs from the microcomputer would automatically adjust the exhaust or inlet air flows by modulating dampers to maintain a negative pressure in the oven. Maintenance of negative pressure in the oven would become the primary control point instead of solvent concentration (percent of the LEL) to prevent solvent laden air escaping from the oven to the working environment. The minimum ventilation air rate would, therefore, be that required to maintain oven pressure instead of reaching the solvent concentration control point in the range of 25 percent to 50 percent of the LEL.

- Dampers and Damper Actuators: Every curing oven is equipped with dampers that would be manually set at start-up. Depending on the site, new dampers must be installed. As a minimum, damper actuators would be installed in order to vary damper positions and, therefore, air flow rates. Actuators would be operated as fail-open or fail-closed depending on site requirements. The microcomputer would provide the signal(s) to each in take and exhaust damper automatically changing position based on analyzer reading(s) or pressure reading(s). The selection of type of dampers and actuators was a site-specific requirement. The software is written, however, to close or open dampers automatically if an unsafe condition develops or if the microcomputer fails.

- Monitor Requirements: Measurements of the inlet and discharge solvent concentrations for the incinerator were also an objective of this project. These readings would also become inputs to the microcomputer and software would be written to calculate destruction efficiency for the purpose of optomizing incinerator operation. Other monitoring needs such as temperature and solvent concentration measurements were judged to be site-specific based on the requirements and configuration of the site. The source and monitoring location must be determined for each installation.

- Utility Supply: Software would be written and sensors provided to monitor the major utility requirements for the system including analyzers and other auxiliary equipment.

EVALUATION AND SELECTION OF MAJOR MICROCOMPUTER HARDWARE AND SOFTWARE

The available microcomputer-based control hardware and software packages were completed based on the conceptual design requirements outlined in the previous section. After initial investigation of specifications from vendors, the following software and hardware packages were evaluated before a final selection was made:

- PROCOM II - BASIC - Computer Products
- EPTAK Controller/ERL - Eagle Signal Systems

- UDAC/SPEAK EASY - Reliance Electric Company
- polyFORTH Software - FORTH, Inc. (software only)
- CAMAC/PASCAL - Kenetic Systems
- INTEL Hardware - INTEL, Inc. (Hardware only)

The major factors considered in the selection of the hardware for the central processing unit (CPU) for the microcomputer included: CPU capacity, directly addressable memory capacity, memory configuration options, memory access speed, I/O port configuration options, interrupt structure, housing and termination options, hardware reliability, operating environment requirements, software packages available, and each vendor's maintenance and service organization. Only with respect to the last two criteria were significant differences perceived at the time of the evaluation during 1980. All five systems provide software packages to aid in the development of process control application programs. Also, the use of development hardware as the prototype control system was required.

The control-oriented BASIC compiler offered by Computer Products with PROCOM II had an advanced BASIC programming language with string functions, bit manipulation functions, and a special communications package designed specifically for their process interface hardware. Process control application programs could be developed on a separate development system called the COMPOSER, which can be configured for program development. The software development effort using the COMPOSER was thought to be too extensive due to the limited number of preprogrammed control functions available with the PROCOM II, BASIC package.

Eagle Signal offered several software development packages for its EPTAK controller. All but one were very similar to the assembly language for the INTEL microprocessor, the CPU used in the EPTAK system. The one exception is ERL, the EPTAK Relay Language, which was evaluated as unsuitable for oven control application because all system functions had to be described via relay ladder diagrams. As with the PROCOM II system, a separate development system would have to be rented to develop the process control application programs.

The Reliance Electric UDAC controller used SPEAK EASY as the process oriented language. SPEAK EASY contained most of the BASIC language statements of the PROCOM II, BASIC package and also had a powerful high-level process/definition capability of the EPTAK software. Software written in SPEAK EASY had a self-documenting quality that would make it very easy to maintain and enhance. Moreover, the hardware used for application program development was the same hardware used to control the system thus obviating any need to rent a development system. However, the critical drawback to SPEAK EASY appeared to be flexibility. The user is locked into the constraints of the language that, in several important cases, is believed to be inadequate for the oven controller design.

CAMAC-8030 software packages that appeared to be most appropriate for the curing oven control application was CAMAC*-PASCAL and CAMAC*FORTH. Both of these were new at the time of development so there would be some added risk concerning reliability.

The polyFORTH software package is marketed by FORTH, Inc. This language was created specifically for control applications. Several utilities that are essential for industrial process control applications were incorporated in the polyFORTH package: multi-tasking, memory management (paging and task swapping), disk management, data base management, target compilation, EPROM burning utilities, report formatting, and many more.

The hardware selection for CPU was based on the vendor's hardware maintenance/service organization. INTEL, in the judgment of the project team, had the broadest support in terms of service, hardware availability and technical assistance. The INTEL/polyFORTH system was selected for the main CPU component of the controller system. In the opinion of the project team, however, a successful control system could have been built with any of the other systems given the resources to build separate development and prototype hardware packages.

ANALYZER SELECTION

The hydrocarbon analyzer was the most critical hardware selection. Analyzers, in general, have not been used extensively by the coating industry for continuous monitoring of curing ovens. Their reliability and accuracy were not well documented. Therefore, a major engineering evaluation was completed to select an analyzer that offered rapid reponse and accuracy, reliability, and compatibility for control. This evaluation was completed by January 1981 and was one of the major tasks because of the need for accurate measurements of solvent concentrations.

Analyzers vary in terms of the methods of detection, types of sample pick-up, and the means of calibration. The four most common detection methods are flame ionization (or combustion), flame temperature, infrared, and catalytic. A brief description of these sensors follows:

- Flame Ionization/Combustion Sensors - Standard flame ionization or combustion sensors measure the electrical conductivity of the products of combustion of the solvent vapor. Positively charged carbon ions produced by burning solvent vapors in a hydrogen flame are collected by a negatively charged electrode. The electrical signal produced is amplified and electrically conditioned and then is compared with a similar signal generated by burning a calibration gas. The sample concentration is read directly in percent of the LEL or parts per million (ppm).

- Flame Temperature Sensors - The flame sensor system utilizes a calibrated pilot flame that burns any flammable gas present in the sample. The increase in flame temperature caused by solvent vapors is measured by a temperature transducer, which develops a signal proportional to the gas concentration. The output meter reads percent of the LEL or ppm. This sensor responds to any flammable compound and maintains accuracy due to its intrinsic design.

- Infrared Sensors - Infrared sensors detect solvent concentration by measuring the amount of infrared absorption the sample exhibits. Nichrome filaments are used as the sources of infrared radiation. Two beams of infrared radiation are passed in parallel through a reference cell and a cell containing the sample. The beams are then focused on detector cells, which measure the difference in the amount of radiation in the two beams. This difference, representing the infrared absorption of the sample, is then amplified and indicated on a meter calibrated in percent of the LEL.

- Catalytic Sensors - In catalytic monitors, resistive heating elements are arranged as two legs of a Wheatstone bridge. The surface of the elements are coated with a precious metal catalyst. When a sample stream containing solvent vapors is exposed to one of the heated elements, the solvents burn on the catalyzed surface raising its temperature and electrical resistance. This condition unbalances the bridge and produces a current flow proportional to percent of the LEL. A direct meter reading displays the percent of the LEL.

A comparison of the various sensor detection methods, including the sensitivity to non-specific hydrocarbons, initial costs, reliability, and temperature limitations, are presented in Table 5. This general comparison considers information supplied by Factory Mutual in their 1979 Approval Guide for equipment, materials, and services for conservation of property. Table 6 also lists the companies contacted for specifications on hydrocarbon analyzers.

Catalytic sensors are the most common detector in general use for ambient air monitoring and some curing oven applications. Price appeared to be the major reason for their selection. Low temperature paint curing ovens could be a suitable application for these sensors. However, the high temperatures

TABLE 5. COMPARISON OF LEL ANALYZER DETECTION METHODS

Detection Method	Sensitivity to Non-specific Hydrocarbons	Initial Cost (Single Sensor only)	Reliability	High Temperature Capability
Flame Ionization/ Combustion	Good to Excellent	High $4,000-13,000	Excellent	Yes
Flame	Good to Excellent	Moderate $3,000-7,000	Excellent	Yes
Infrared	Poor	High $4,000-10,000	Good (Potential Masking Problem)	No, 120°F Limit
Catalytic	Good	Low up to $2,500	Poor (Due to Poisoning)	Yes, 600°F Limit

Effective Date of Prices June, 1980

Price Vary With Options for Application

TABLE 6. VENDORS CONTACTED FOR INFORMATION ON LEL ANALYZERS

Manufacturer	Model #	Type	Approx Price $ **	Remarks
Ratfisch Instruments New York, N.Y.	RS-555	Flame - Ionization	28,430	Multi-channel (8) with vacuum sample pump
	RS-55	Flame - Ionization	9,635	Single channel with self-check & vacuum sample pump
Despatch Industries (utilizing a modified Control Instruments Corporation sensor) Minneapolis, Minn.	ENERSCAN	Flame	13,000	Single channel with self-check & vacuum sample pump
Control Instruments Corp. Fairfield, N. J.	CCS	Catalytic	1,140	Air aspirator sample
	FFA	Flame	3,360-4,800	Air aspirator sample
Leeds & Northrup North Wales, Pa.	7867	Catalytic	Not Avail.	Standard industrial control system available as option
Universal Sensors and Devices, Inc. Chatsworth, Calif.	HY-100	Catalytic (Low Temp. 100°F Max)	1,150	Single channel
	HY-200		1,200	Dual channel
	HY-400		2,200-2,700	Four channel
Erdco Engineering Corporation	Series 25D	Catalytic	Not Avail.	Single or Multi channel, air aspirator sampling
MSA (Mine Safety Appliance	202	Infrared	4,920*	Air aspirator sampling, self-zeroing
	303	Infrared	3,600*	
	511	Catalytic	1,150	
Scott Aviation Lancaster, NY	9000	Catalytic	1,250-1,850	Air aspirator sampling, self-zeroing
	9700	Catalytic	2,600	
Dictaphone Mountain View, CA	810	Catalytic	1,320	Single or dual channel, remote calibration
	820	Catalytic	1,670	
Bacharach Instrument Co. Mountain View CA	CD 800W	Catalytic	Not Avail.	Single, dual, or four channel with optional high reading selection
	CD 802W	Catalytic	Not Avail.	
	CD 850	Catalytic	1,950	
General Monitors, Inc. Costa Mesa, CA	480	Catalytic	1,240	Diffusion sampling, single channel
Beckman Instruments Fullerton, CA	400	Flame - Ionization	12,000	Positive pressure pump sampling, heated analyzer
	402			

* Excludes cost of sampling system

** Effective date of prices June 1980

normally encountered in curing ovens and poisoning of the catalyst by process fumes appeared to offer major problems. Poisoning of the catalyst would produce a low reading of the solvent concentration thus reduce safety. Solvents in curing ovens contain lead, silicones, plasticizers, or halogens and can destroy the catalyst in a matter of hours. Daily maintenance and calibration would be needed to assure a safe and efficient operation. Due to the potential problems of poor reliability and daily maintenance, this sensor was ruled out for the system design. Also, tests conducted by the Naval Research Center (Reference 9) found their accuracy for measuring percent of the LEL to be much poorer than flame ionization detectors.

Infrared sensors generally should be used for applications containing a single solvent, since they must be used for measuring a specific hydrocarbon. This appeared to rule out the use of this type of sensor for the curing oven control systems since typical coating plants utilize a wide variety of solvents and coating formulations. In addition, sample conditioning to reduce the temperature of the sample that must be phased through the IR detector could have led to condensation in the sample lines.

Flame ionization (FID) and flame temperature detectors appeared to have excellent sensitivity and good discrimination of different hydrocarbons. Both systems have been used for some applications in curing ovens and for sampling incinerator exhaust gases up to temperatures of 871°C (1600°F). They are insensitive to non-hydrocarbon gases and contaminants. These analyzers have the best performance in terms of maintenance and can be employed in situations where particulates and high boiling resins are present by proper design of sample handling equipment. These analyzers have had the greatest success of any analyzer in the curing oven application area.

Each analyzer requires a pump or aspirator to provide flow of sample through the instrument from the sampling points. The calibration of all types of each sensor is accomplished by injecting a sample of calibration gas available from the sensor manufacturers and specialty gas suppliers.

Safe operation of a ventilation air flow controlled curing oven is dependent on the sensitivity, reliability, and stability of the LEL analyzer. Based on the initial results of this engineering evaluation, LEL analyzers considered suitable for the microcomputer control system, were the flame ionization or flame temperature type sensors. The primary candidates were narrowed down to the Ratfisch flame ionization detectors and the Despatch ENERSCAN and Control Instruments' flame temperature analyzers because these units had been used by the industry.

These analyzers all utilize vacuum pump sampling. However, two major differences in the sample handling system existed: the maximum design length of the sample pick-up lines and single sample versus continuous multi-sample monitoring. One of the FID's offered by Ratfisch Instrumente, RS-555, had a package unit containing eight continuous FID's. Ratfisch claimed that sample line run lengths of up to 9.14 m (30 feet) could be handled by their units. Despatch Industries and Control Instruments analyzers utilize continuous, single-point monitoring requiring multiple units for multi-point sampling. Also, the sample line lengths were limited to a maximum of 1.52m (5 feet) which would require local mounting near the point of sampling instead of a central location for the analyzer(s).

The flame ionization principle of operation also was found to give accurate determination of the percent of the LEL (Reference 9). In the Ratfisch model, the flame tip temperature is higher than with other FID's because a ceramic tip is used for the FID burner. At the higher temperature, Ratfisch claimed that a linear relationship exists between the actual percentage of the LEL and the electrical output signal from the FID. This point and the multichannel unit strongly influenced the decision to select this particular analyzer since it was emphasized that an analyzer that did not require recalibration with every formula was required. The Ratfisch model gives a reading in percentage of the LEL for a wide range of solvents thus reducing the need for recalibration as coating formulations are changed in the curing process.

In the FID analyzer, the hydrocarbon molecules are split into CHO^+ radicals as they pass through the burner flame. These positively charged ions pass between the electrodes under a 200-volt potential. Electrons are drawn from the electrodes thus neutralizing the positive ions. The electrons released by the electrodes produce a very small current that is amplified in the analyzer electronics section.

The Ratfisch flame ionization detector analyzer was finally selected for the microcomputer control system for two primary reasons: accuracy and multiple channel measurement. The single unit package provided continuous multiple point measurements and resulted in reduced capital costs by being able to locate the unit at one control location in the plant.

EVALUATION OF THE APPLICABILITY OF CONTROL TO A FACILITY

The industrial survey prior to the design of the prototype system verified that many facilities could benefit from computer control and provided the information needed to ensure that the prototype design would handle emission characteristics common to the typical coating applications. This section discusses the evaluation steps necessary to determine the applicability of control for a facility and presents a generic conceptual design for the miscellaneous metal parts industry. The same approach was used to select the system demonstration site.

The control system tailored to meet site-specific requirements could be applicable to both retrofit installations and to new installations. Modification and installation requirements are generally keyed to process requirements, e.g., number of oven heating zones, type of air flow control, heat recovery, oven design and existence of incinerators.

A microcomputer-based control system can be designed to match site-specific requirements for most curing oven systems using solvent-base coatings. The safety and control functions can be incorporated with the major consideration being number of oven zones requiring control and the dynamics of the process. This means that the investment costs would become a function of the number of zones and site-specific processing requirements.

The decision to install a computer control system would be dependent on economics and safety. The first step is a site survey that would determine the design conditions which would also firm up any initial economic projections for the control system. As previously discussed (Figure 2), it is simple to make the initial projection of oven fuel savings based on some easily obtainable information, such as existing ventilation air flow rates, exhaust air temperature, and solvent loadings. If an incinerator is already installed, then the savings projection should include fuel savings for the incinerator once the control system is installed. If incinerators must be installed to meet VOC emission control regulations, then the economic projection should include a capital cost comparison of investment savings with control system as well as the total energy savings for the oven and incinerator with and without control system.

Site Analysis of Processing Conditions and Costs

Following the initial evaluation, a plant considering this system should complete a plant survey. This plant survey would include the following steps to evaluate the conditions existing at a facility:

1. Measurement of existing solvent concentrations in each zone of the oven, exhaust ductwork, and at any other point where emission control is required or for any other air stream entering the oven such as from a fume tunnel, spray booth, etc. A suitable hydrocarbon analyzer properly calibrated should be used for these measurements. Measurements must be taken to cover the range of coatings employed during production.

2. Accurate air flow rates must be determined. Air flow rates would be measured for combustion air, ventilation air flow rates for each exhaust duct, and at the entry and exit of the oven.

3. Temperatures must be measured using a thermometer or thermocouples for each exhaust duct and for the incinerator if one is installed.

4. Pressures must be measured at the product entrance and exit ends of the oven using a draft manometer.

The second step is to determine the air flow rate that could be achieved with the control system. The minimum air flow rate is the rate which will maintain a negative pressure in the oven (no air escaping from the entry or exit of the oven). This test is run without solvent in the oven and at the oven curing temperatures used for existing production curing requirements. Steps 2 through 4 are repeated once the minimum air flow rate is obtained by closing each oven exhaust damper.

The results from this survey follow:

- Maximum oven fuel savings equal energy required at existing ventilation air flow rates minus energy required at minimum air flow rates
- Maximum percent of the LEL under control equals maximum measured solvent concentration as percent of the LEL times existing air flow rate divided by minimum air flow rate
- Pressure sensor range equals pressures measured at existing and at minimum air flow rate
- Incinerator energy savings equal calculations based on temperature and air flow measurements and solvent concentrations with and without control (Refer Reference 2)
- New incinerator design criteria: Oven exhaust temperature range; range of solvent concentration without control; range of solvent concentration with control; Maximum/minimum air flow rates

At this point quotations for the specific hardware can be obtained from vendors. The plant at this stage, however, should consider its overall needs in terms of configuring the control system for both monitoring and control. The following minimum requirements and then options that can be included with the control system are:

Minimum Requirements

- Analyzers must be installed for continuous measurement of solvent concentration in each zone of the curing oven with sample probes located at points of highest solvent concentration (percent of the LEL)
- Fail Safe - The system must meet standards of the NFPA Codes
- Pressure sensors must be installed in each oven opening to assure maintenance of negative pressure under control
- Existing dampers with actuators or new dampers must be installed to permit adjustments in air flow rates under control
- Utility services must be provided to meet the specifications of the control and monitoring equipment

Optional Requirements

- Temperature sensors can be installed with the control system to provide continuous readings of curing oven and incinerator temperatures
- Analyzers can be installed to monitor incinerator destruction efficiency or solvent concentrations in the work area from spray booths or from any other emission source

Generally, continuous curing ovens presently operating above 1.8 m^3/s (3,500 $stdft^3/min$) of ventilation air flow having one or two zones would justify control. For higher ventilation air flow rates, such as used in the coil coating industry, the number of zones requiring control can range from two to five. Economic projections for costs of control systems and energy savings for curing and incineration are shown in Section 5.

Potential Installation Problems

As in any new application, there are potential problems if the installation is not made with a detailed knowledge of the technology. It is important that the oven dynamics be fully understood and that good process engineering practices be carefully followed. This section discusses the four areas for which critical design practices are essential.

- Oven Design: As discussed under Control Concepts and Project Approach the solvent evaporates from the applied coating so as to create a peak solvent concentration in the oven. This is the concentration that must be controlled. While the point of maximum solvent evolution is dependent upon the type and amount of solvent used, it is also strongly influenced by the flow pattern in the oven. Previous studies have shown that flow patterns vary greatly between ovens and with different coatings. In addition, ovens that have significant air leaks can influence control response. Before installing a control system, it is essential that the flow patterns in the oven be accurately determined.

- Probe Placement: Since the solvent concentration forms a longitudinal profile through the oven which changes with the coating being applied and the operating conditions, sample probe placement is very important. Twelve probes were used in the Mack Truck installation since it was a prototype installation. However, a minimum of one probe per zone is recommended for any control application depending upon the number of zones in the oven. These probes should be placed in well mixed areas in the mainstream of the gas flow. A single probe is not adequate for control in any but the very simplest of ovens.
- Analyzer Accuracy: An analyzer that is reliable over a long period of time is essential. Drift through catalyst poisoning or other problems is not acceptable in a control situation. To ensure continued accuracy, it must be capable of easy calibration. In the plant surveys conducted during this project, many instances were found of low LEL readings resulting from reduced sensitivity in the catalytic analyzers. This, combined with the unlikelihood of a single probe finding the peak concentration over a range of operating conditions, points out the necessity of close attention to oven dynamics.
- Damper Design: The damper system is critical to the safe control of the oven. Dampers must be placed and sequenced to provide dilution air effectively when called for by the controller. In addition, the dampers must be designed to fail in a safe condition. Depending upon the oven dynamics, failing safe may imply failing in the closed position for some dampers and the open position for others.

GENERIC SYSTEM CONFIGURATION

Although the final design of the prototype contained some features that applied specifically to Mack Trucks, the industry survey and a large part of the design work were devoted to developing generic configurations that would be applicable to a wide range of plants in this industry. It is important to stress, however, that although it is possible to provide a generic system, the variation in the operating practices, oven conditions, and coating formulation will require some custom engineering in nearly all cases.

Figure 6 shows the major features and Table 7 describes the equipment and their function that would be common to almost all oven control systems for the industry evaluated during this project:

- Sampling probes and sample handling systems must be used with hydrocarbon analyzers.
- A microcomputer with software containing all the control logic and system and analyzer checks.
- Damper activators which open and close air dampers to minimize the amount of air required.
- Good oven sealing practices, to minimize the influx of sufficient air through the oven joints and exit/entry points. Air entering the oven from these sources is not available to the control system for optimization of air flows.
- Pressure sensors to maintain a negative pressure in the oven.

FAIL SAFE REQUIREMENTS

As discussed in Safety Analysis, under System Design, considerable attention was given to the fail-safe requirements of the control system in case of power, analyzer, or other failures. Table 4 lists the system action necessary in the case of specific component failures or solvent excursions above 50 percent of the LEL.

The basic fail-safe condition stops the plant coating line by shutting off the coating operation, placing all dampers in a position to provide the maximum amount of ventilation air to the most likely area of highest solvent concentration, stopping the parts line, and shutting off fuel to oven burners for direct-fired ovens. These actions minimize the chance of an unsafe condition ever developing in the case of system failure.

SELECTION OF THE DEMONSTRATION HOST SITE

The EPA, DOE, and CCA's project team established the site-selection criteria for testing the prototype. The final sites were identified from the industrial survey described. Based on the conceptual design for the control system, the following

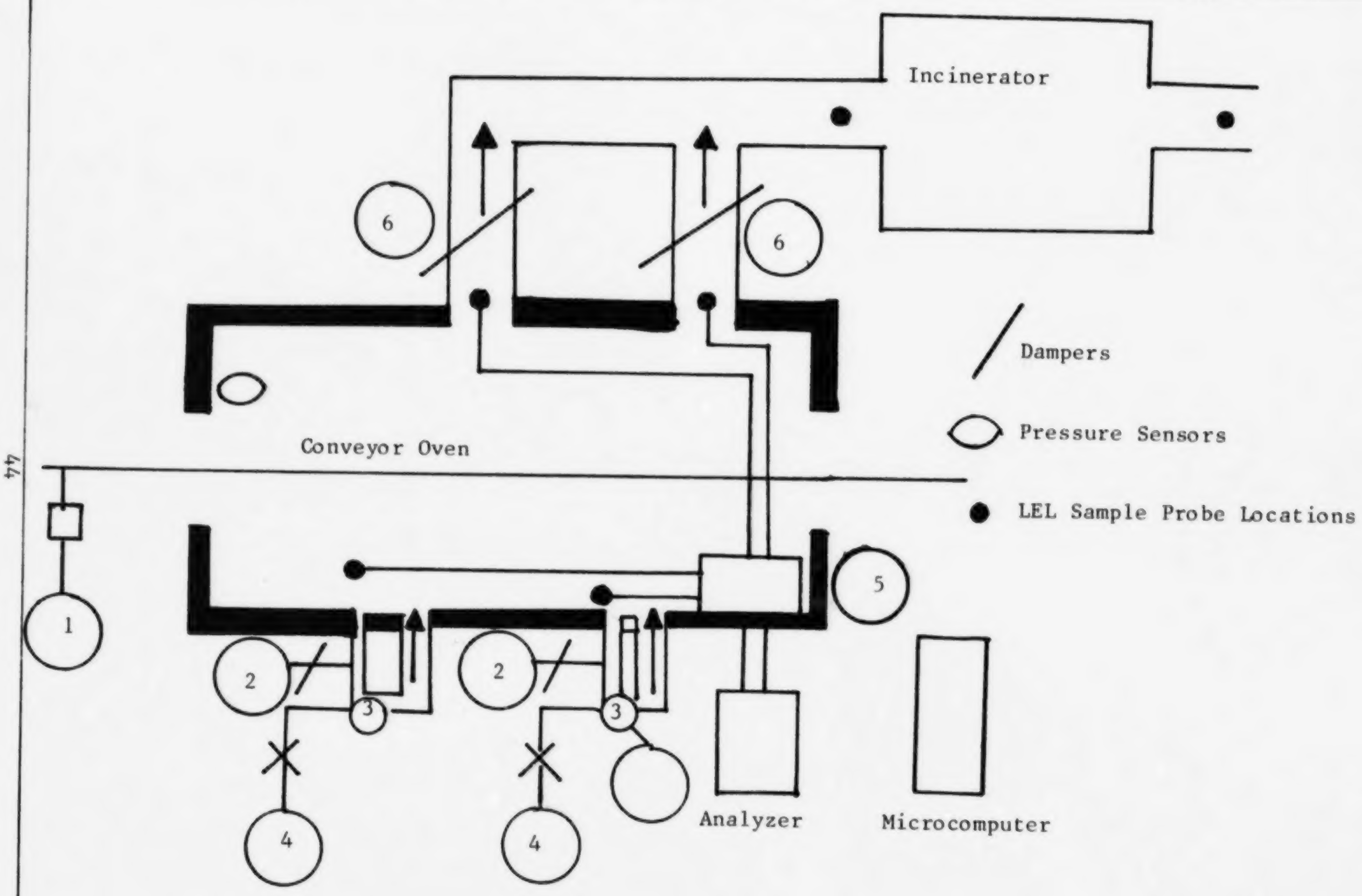

Incinerator
6
6
Dampers
Pressure Sensors
Conveyor Oven
LEL Sample Probe Locations
1
5
2
2
3
3
4
4
Analyzer
Microcomputer

Figure 6. General Arrangement for control System, Conveyor Oven with Incinerator (Refer to Table 7 for Description)

TABLE 7. DESCRIPTION OF COMPONENTS FOR GENERIC CONFIGURATION

(Refer Figure 6)

LEL Sample Points

- One for each zone located in recirculation ductwork, Item 3
- One for each zone exhaust
- Optional:
    - One for entry to incinerator
    - One for exhaust from incinerator

Item	Description	Function
1.	Conveyor Interlock	Shut off in event of solvent excursion or malfunction of controller
2.	Dampers and actuators for each make-up air system	Pressure and air flow rate control
3.	Fan and burner	No control function, existing on oven
4.	Fuel flow interlock	Shut off fuel in event of excursion
5.	Prefilter station	Initial filtering of samples in oven
6.	Dampers and actuators	Control exhaust air flow rate and pressure
7.	Analyzer	Continuous monitoring of solvent concentrations
8.	Microcomputer	All safety and control functions

criteria were established by the project team to provide guidelines for the final selection of a host site:

- Type of Oven - A continuous curing oven processing small metal fabricated parts with two or more zones would be selected.
- Type of Coating - Solvent-based coatings which would require use of VOC emission control equipment.
- Incineration - A thermal or catalytic incinerator had to be installed and operating prior to the installation of the prototype control system.
- Economics - The existing operating conditions for the curing operation would be typical of those commonly found in the metal parts industry and would show cost savings achievable by ventilation air flow rate reductions.
- Product Quality - Many coating industry experts believed that a significant reduction in ventilation air flow rates could lead to product quality problems. Therefore, the site selected for the prototype had to have the analytical support to determine the effect on product quality and had to agree to testing the effects of reduced ventilation air flow rates on product quality if these effects became evident.
- Heat Recovery Equipment - A site having heat recovery systems in place with an incinerator would be given priority in order to assess any problems associated with operation of heat recovery systems once ventilation air flow rates were decreased by the control system.
- VOC Regulations - The industrial firm would have existing or pending regulations for VOC emission reductions.
- Cost Share/Publicity - The cost share would include a financial contribution for the equipment, technical, and analytical support. Also, the industrial firm would have to agree to conduct two on-site seminars and to permit reporting of all non-confidential results of the project.

The criteria were then ranked by the project team in order of importance for the prototype demonstration as shown in Table 8. Each of the eight criteria was assigned a weight factor ranging from 0.075 to 0.20, which was based on the relative

TABLE 8. HOST SITE CRITERIA FOR SELECTION

	Criteria		Subjective Estimate		Weight Factor	Yes/No Factor
1.	Cost Share	a.	1.0	>50%	0.2	1
		b.	0.75	25-50%		1
		c.	0.5	0-25%		1
2.	Incineration	a.	1.0	Existing	0.2	1
		b.	0.5	Considering		1
		c.	0.0	No		1
3.	High Performance VOC Coating	a.	1.0	Yes - High Perf.	0.15	1
		b.	0.75	No - High Perf.		1
		c.	0.0	No - VOC		0
4.	(Oven & Incinerator) Economics Favorable	a.	1.0	0-2 yr payback	0.10	1
		b.	0.75	2-3 yr payback		1
		c.	0.5	>3-yr payback		1
5.	LEL Limit based on product quality	a.	1.0	No limit 35 to 50%	0.10	1
		b.	0.75	25-34%		1
		c.	0.0	<25%		1
6.	Heat Recovery	a.	1.0	Exist WHB	0.10	1
		b.	0.75	Heat Sink		1
		c.	0.25	No Heat Sink		1
7.	Subjected to State VOC Regulations	a.	1.0	Pre-1/82	0.075	1
		b.	0.75	Post-1/82		1
		c.	0.25	Unsure		1
8.	Continuous Curing Oven (metal parts)	a.	1.0	Yes	0.075	1
		b.	0.0	No		0
		c.	0.0			0

importance of the individual criterion. In addition, each of the eight criteria had included a choice of three subjective estimate factors. A Yes/No factor was assigned to each subjective estimate factor. The purpose of this factor was to emphasize the criteria that must be met. Only two No factors were included in this initial assessment. These were VOC in the coatings and a continuous curing oven in the miscellaneous metal products industry. The second No factor eliminated the coil coating and fabric/paper coating companies who had indicated an interest in being the host site.

Based on this assessment, the Mack Trucks, Inc., Building 514 Assembly Plant in Allentown, Pennsylvania was approved by DOE and EPA as host site for the prototype. This facility was chosen for the following reasons:

- The dip oven is a continuous two-zone oven that cures small truck parts and is representative of the types of curing ovens found in the targeted industry.
- Solvent coatings are used.
- A catalytic incinerator was in operation to meet environmental regulations
- Ventilation air flow rate reductions could be achieved to lower fuel costs for the curing oven and the incinerator
- Mack Trucks agreed to both share the cost and to provide the support of technical and operating personnel during start-up and for monitoring results
- Some of the energy from the incinerator exhaust gases is recovered with a heat exchanger to provide heat for a curing oven
- Mack Trucks agreed to host two on-site seminars to present the results of the project to industry and to permit reporting of the results

DESCRIPTION OF MACK TRUCKS' FACILITY

The general arrangement for Mack Trucks' curing oven system before retrofit of the controller in Building 514 is shown in Figure 7. The curing line was installed in 1977. Schweitzer Industrial Corporation supplied the curing ovens and incinerator. All ovens are conveyor types. The oven cures painted small parts for trucks.

The ventilation air from the prime, color, and dip ovens is exhausted to the inlet of a catalytic incinerator. These ovens are indirectly heated with steam. No. 2 fuel oil is used for

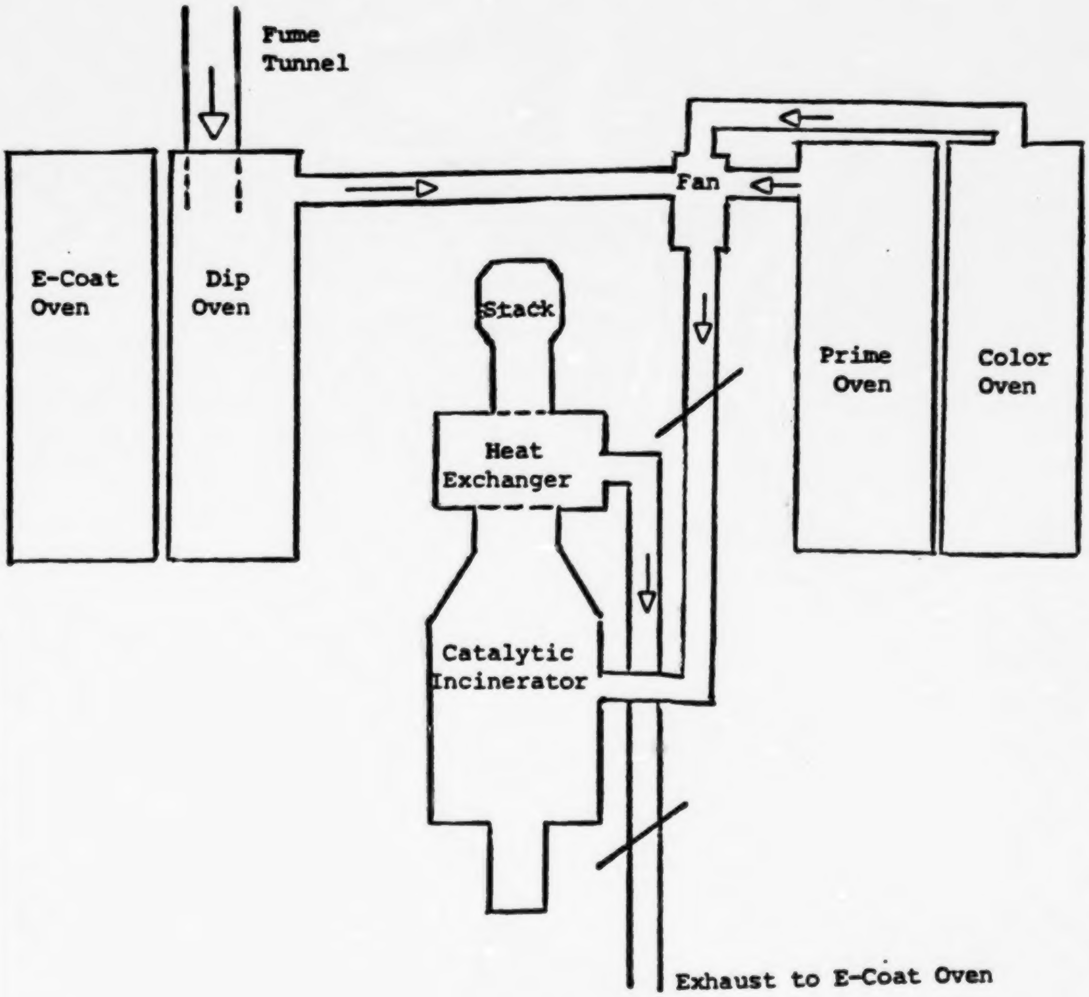

Fume Tunnel
E-Coat Oven
Dip Oven
Fan
Stack
Prime Oven
Color Oven
Heat Exchanger
Catalytic Incinerator
Exhaust to E-Coat Oven

Figure 7. - Mack Trucks Curing Line Layout Before Retrofit

the incinerator. The exhaust gas from the incinerator is used to heat the air for curing parts in the E-coat oven. The dip oven was selected by Mack Trucks to test the prototype because of its solvent loadings and close proximity to the incinerator.

System Installation

Engineering for retrofitting the Mack Trucks facility involved the selection of final hardware components, scheduling of major tasks to complete the installation, specification of control system logic and requirements and finalization of software for the control system. Figure 8 shows the general configuration of the system after retrofit and Table 9 lists the major equipment selected by the project team for Mack Trucks. Mack Trucks had the field installation work completed by a subcontractor, East Penn Mechanical Company, based on the installation drawings and field instructions (See Appendices E and F).

Description of Major Hardware and Application

As shown in Table 9, the major equipment included dampers, damper actuators, electrical to pneumatic (I/P) convertors, hydrocarbon analyzers (flame ionization types), filters, heated sample lines, and temperature sensors. Detailed drawings of the installation are shown in Figures 9 through 13. This section describes the function of the major equipment shown in these figures and the reasons for their use:

- Temperature Sensors - Temperature sensors were installed to provide continuous readings for the following process conditions:

    - Dip Oven Ventilation Air Temperature - This temperature was measured and displayed on the CRT. This temperature reading was used to calculate the sensible heat demand for ventilation air heating in the dip oven.

    - Fume Tunnel Temperature - The parts for the dip oven are conveyed to the dip oven through an enclosed fume tunnel. The exhaust from the fume tunnel is vented to the incinerator. A temperature sensor was installed at the inlet to the dip oven (end of the fume tunnel) to monitor rise in temperature after the ventilation air flow rate was reduced under control. If the temperature increased, it would indicate that the air from the front of the dip oven was being forced back into the fume tunnel. That would mean a pressurization of the oven under control in that location. A temperature reading was used in lieu of a pressure sensor since it wasn't possible to locate a pressure sensor in the fume tunnel. This temperature was also displayed on the CRT.

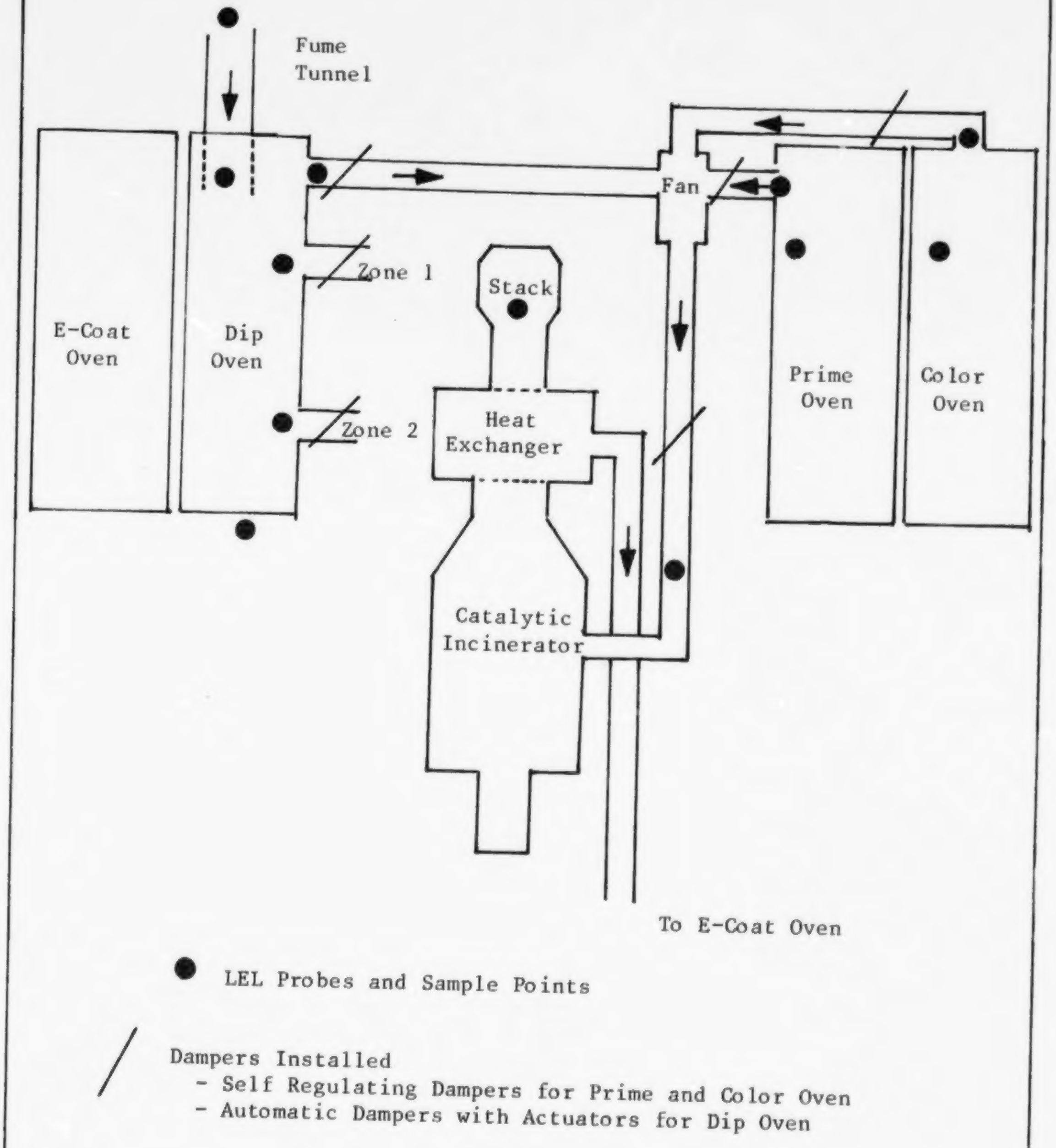

Fume
Tunnel
Fan
E-Coat
Oven
Dip
Oven
Zone 1
Zone 2
Stack
Heat
Exchanger
Catalytic
Incinerator
Prime
Oven
Color
Oven
To E-Coat Oven
● LEL Probes and Sample Points
/ Dampers Installed
- Self Regulating Dampers for Prime and Color Oven
- Automatic Dampers with Actuators for Dip Oven

Figure 8. - Schematic of Mack Trucks Installation
Shwing Damper and Sample Probe Locations

TABLE 9. MAJOR EQUIPMENT LIST - MACK TRUCKS' INSTALLATION

Item/Number	Vendor Name	Description/Comments
Temperature Sensors/5	Omega Engineering	Type K, Model NBI-CAIN-316u-18
Pressure Transmitter/1	Setra	Model C239
Hydrogen Generator/1	Laboratory Data Control	Model 92004301
Self-regulating Damper/3	Metal-Aire	Model 212-TH
Control Damper/3	Metal-Aire	Model 212-TH
I/P Convertors/3		
Heated Sample Lines/10	Technical Heaters	Models LP212-4-12(8), LP212-4-20, and LP212-4-28
Heated Prefilters/2	Ratfisch Instrumente	Stainless Steel Sintered Metal Filter, 5 micron
Prefilter Station/2		
- Filter Elements	Ratfisch Instrumente	Stainless Steel Sintered Metal Filter, 5 micron
- Air Eductor	Mott Metalurgical	Model 501869
Analyzers/2	Ratfisch Instrumente	Model RS-555/8 and RS-555/4
Microcomputer/1	Intel	Model SBC 86/12A; CS 80, SBC 534, SBC 732
CRT/1	Intelligent Systems Corp	ISC 8001G
Printer/1	Texas Instruments	TI810
Span Gas/1	Air Products	8000 ppm Methane in Air, 3000 ppm Propane in Air
Control Room/1	EPM	Enclosure for analyzers and microcomputer

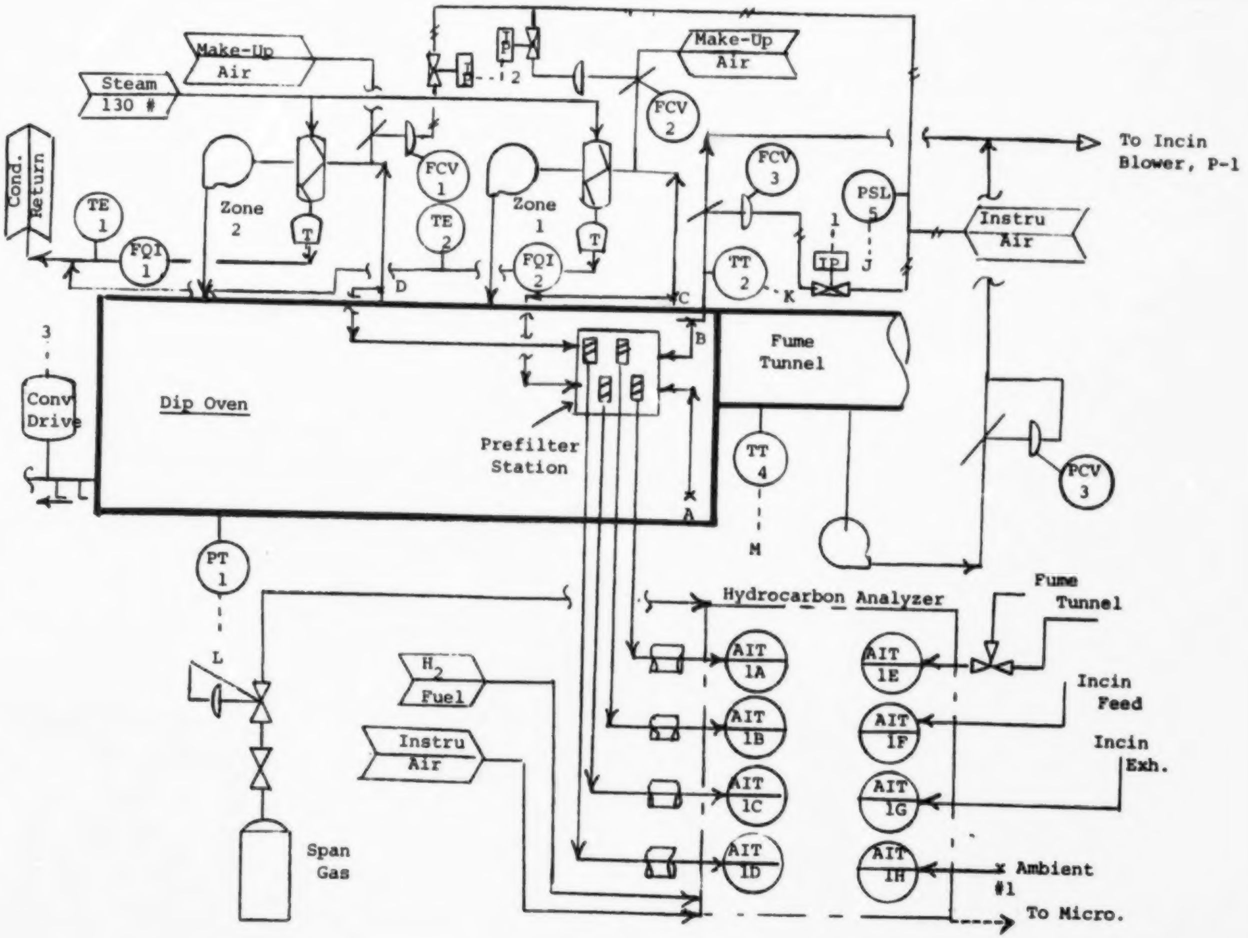

Make-Up Air
Steam 130 #
Cond. Return
TE 1
FQI 1
Zone 2
T
FCV 1
TE 2
D
Zone 1
FQI 2
T
2
Make-Up Air
FCV 2
C
FCV 3
TT 2
K
1
TP
J
PSL 5
To Incin Blower, P-1
Instru Air
3
Conv Drive
Dip Oven
B
Prefilter Station
A
Fume Tunnel
TT 4
M
PCV 3
PT 1
L
Hydrocarbon Analyzer
Fume Tunnel
H2 Fuel
Instru Air
AIT 1A
AIT 1B
AIT 1C
AIT 1D
AIT 1E
AIT 1F
AIT 1G
AIT 1H
Incin Feed
Incin Exh.
Ambient #1
To Micro.
Span Gas

Figure 9. Detailed Schematic of Dip Oven
(Refer to Figure 13 for Key to Symbols)

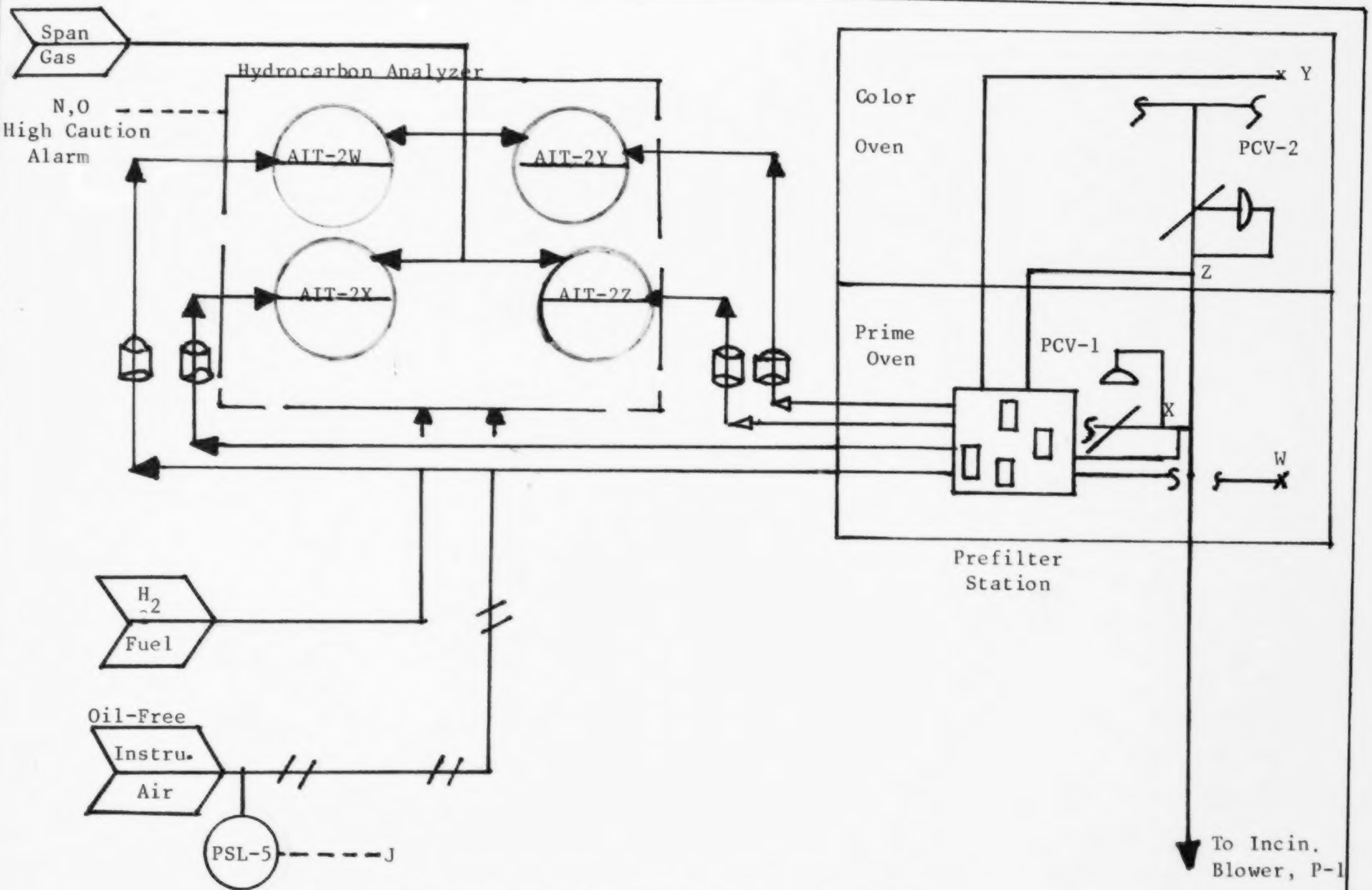

Span Gas
Hydrocarbon Analyzer
N,O High Caution Alarm
AIT-2W
AIT-2Y
AIT-2X
AIT-2Z
Color Oven
Prime Oven
PCV-2
PCV-1
Y
Z
X
W
Prefilter Station
H_2 Fuel
Oil-Free Instru. Air
PSL-5
J
To Incin. Blower, P-1

Figure 10. Detailed Schematic of Prime and Color Ovens
(Refer to Figure 13 for Key to Symbols)

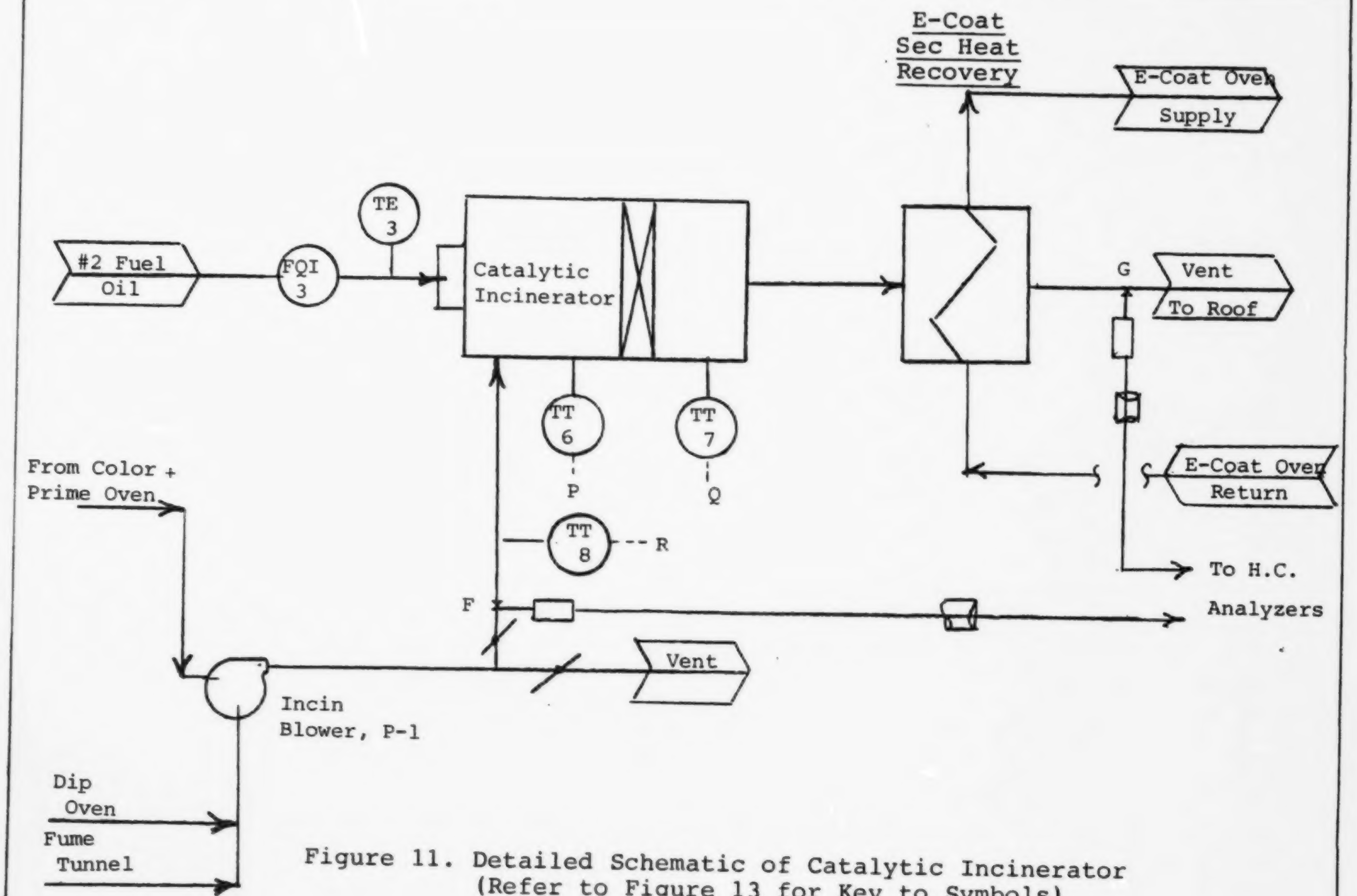

E-Coat
Sec Heat
Recovery
E-Coat Oven
Supply
TE
3
#2 Fuel
Oil
FQI
3
Catalytic
Incinerator
G
Vent
To Roof
TT
6
TT
7
P
Q
E-Coat Oven
Return
From Color +
Prime Oven
TT
8
R
To H.C.
Analyzers
F
Vent
Incin
Blower, P-1
Dip
Oven
Fume
Tunnel

Figure 11. Detailed Schematic of Catalytic Incinerator
(Refer to Figure 13 for Key to Symbols)

Inputs to Micro (1

From Analyzer AIT-1

Ⓐ Primary D.O. Air Seal
Ⓑ D.O. Exhaust
Ⓒ D.O. Zone 1
Ⓓ D.O. Zone 2
(E_1) Fume Tunnel Exhaust
(E_2) Fume Tunnel Exit
(E_3) Fume Tunnel Auxiliary
Ⓕ CPD Combined
Ⓖ Incin Exhaust
Ⓗ Ambient
Ⓘ Power Status

From Dip Oven

Ⓙ PSL-5
Ⓚ TT-2
Ⓛ PT-1
Ⓜ TT-4

From Analyzer AIT-2

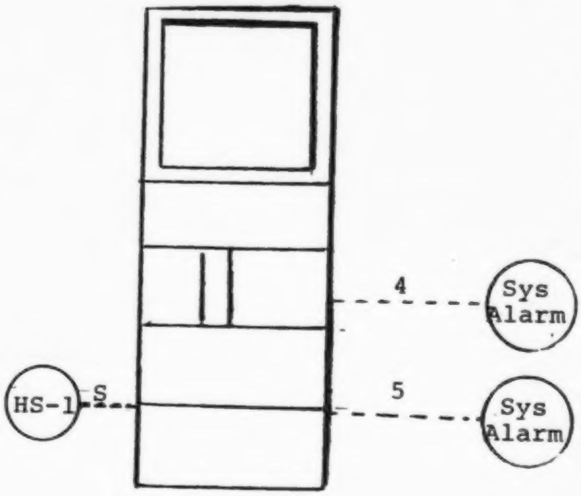
Ⓝ High Caution - 2X
Ⓞ High Caution - 2Z

From Incinerator

Ⓟ TT-6
Ⓠ TT-7
Ⓡ TT-8
Ⓢ Alarm Disengage

Outputs from Micro (1

① I/P - FCV-3
② I/P - FCV-1+2
③ Conveyor Drive
④ System Alarm, Caution Light
⑤ System Alarm; Alarm Sound + Shutdown



Micro-Computer Controller

1) Refer to Figures
C = Color Oven
P = Prime Oven
D = Dip Oven

Figure 12 Microcomputer Inputs and Outputs

KEY TO SYMBOLS

- - - - - -	–	Electrical wire
—//—	–	Pneumatic lines
T	–	Steam Trap
▨	–	Sample Prefilter
AIT	–	Analysis Indicating Transmitter
PSL	–	Low Pressure Switch
PCV	–	Pressure Control Valve
FCV	–	Flow Control Valve
TT	–	Temperature Transmitter
TE	–	Temperature Element
FQI	–	Flow Totalizing Indicator
I/P	–	Current to Pneumatic Converter
HS	–	Hand Switch

Figure 13. Key To Symbols For Figures 9 to 12

  - Incinerator Temperatures - Three temperature sensors were installed for monitoring performance of the catalytic incinerator. These temperatures were used to calculate fuel demand to supplement readings taken from the fuel oil meter. The temperatures were measured for the combined air streams entering the incinerator, the inlet temperature to the catalyst bed and the exhaust temperature from the catalyst bed. These temperatures were also displayed on the CRT.

- Pressure Sensor - The pressure sensor was installed in the exhaust of the dip oven. This sensor was used to control make-up air flow rate and ventilation air flow rate to monitor a negative pressure in the dip oven. The control set point was -2 in H_2O and the range of the sensor was 0 to -6 in H_2O.

- Analyzers and Sampling Location Selection - Two Ratfisch hydrocarbon analyzers were used to monitor the solvent concentrations: the Model RS-555/8, an eight-channel unit, and Model RS-555/4, a four-channel unit. Each unit included an oven detection unit where flame ionization detectors were located and an electronics unit for control of each detector.

  The Model RS-555/4 was used to monitor the exhaust concentration at the point where the parts first entered the ovens in the color and prime ovens. The analyzer has a high-level alarm feature that was used to sound an alarm if the solvent concentration exceeded 45 percent of the LEL at any time during the prototype testing. The LEL status of the prime and color ovens was displayed on the CRT. These monitoring points would not be required for a control system for plants where a common exhaust to an incinerator is not present.

  The Model RS-555/8 unit was used to control the dip oven and to monitor the destruction efficiency of the the incinerator. Continuous measurement of the solvent concentration (percent of the LEL) for the dip oven and incinerator was performed in the recirculation ductwork for Zone 1 and Zone 2, the dip oven inlet, the dip oven exhaust, the fume tunnel inlet, the fume tunnel exhaust, the incinerator inlet, the incinerator exhaust and the ambient air above dip oven.

  Sampling locations inside the dip oven was selected to assure that the highest concentrations were being monitored and controlled. Sampling at the recirculation ductwork was representative of the concentration in each zone since the recirculation blowers were operated at 9.44 m^3/s (20,000 $stdft^3/min$) thus assuring a representative sample due to the high recirculation rate. The entry points were selected to be located in the area where the parts were being initially cured. The exhaust point gave the average concentration leaving the dip oven to the incinerator. Readings were displayed on the CRT.

Control of the ventilation air flow rate was based on the highest solvent concentration. Also, by placing multiple sampling points in the oven, failure of one detector assured safety since they provided backup measurements.

The measurement of solvent concentrations before and after the incinerator provided a means to calculate the destruction efficiency of the catalytic incinerator. The destruction efficiency was displayed on the CRT.

- Damper Requirements - The Mack Trucks installation before retrofit had no damper in the exhaust ductwork of the prime, color, and dip ovens. Dampers were installed at the suction side of each recirculation fan in Zones 1 and 2 to provide fresh outside air. A damper was also installed at the exhaust of the fume tunnel.

  A flow direction damper and a flow regulator damper were located where ventilation air was discharged from from the prime, color, and dip ovens. These dampers were manually set after initial start-up of the line in 1977 and remained in place after retrofit was completed.

In order to control the air flow rates entering and leaving the dip oven and to reduce the air flow to the incinerator, the following dampers were installed:

- Self-regulating Dampers - Three self-regulating dampers were installed, one each at the exhaust of the prime and color ovens and one for the exhaust of the fume tunnel to maintain a constant volumetric flow of air from those three sources as the air flow rate from the dip oven was automatically reduced by the controller. Without these dampers, additional air would have been exhausted from those sources which would have decreased the incinerator fuel savings.

- Control Dampers - In addition to the self-regulating dampers, new dampers equipped with actuators and I/P convertors were installed in the exhaust duct and two make-up air ducts entering the oven in the suction line of each recirculation fan. The I/P convertors receive the electrical signal from the analyzer or microcomputer and change the air pressure on the pneumatic actuator to vary each damper position. A mechanical stop was placed on the damper arm of the exhaust damper to prevent complete closure. The actuators are designed to open automatically if the signal from either the microcomputer or analyzers is lost or when solvent concentration exceeded the safe limit. This action returned the air flow rates to their original values before the dip oven was retrofitted with the control system.

Sample Handling Equipment for Analyzers

Although all of the major equipment is designed to provide reliable operation, the design of the sample handling equipment for the analyzers was considered extremely important. The response time and maintenance of sample integrity was necessary to assure accurate readings of solvent concentrations from each point in the system. The design of this equipment was completed by the project team in consultation with the analyzer suppliers. Plugging and condensation in the sample lines were the primary concern. The types of systems selected for sample handling were prefilter stations, heated prefilters and heated sample lines.

The prefilter stations (Refer Appendix F) were designed for sampling of the solvent concentrations within each oven. The prefilter station where centrally located at a point inside an oven from which the sample could be drawn through a heated line to the analyzer.

A sample probe [1.52 m (5 feet) long, 0.1 m (1/2-inch) diameter stainless steel tubing with ten 0.002 m (1/16-inch) holes at 0.15 m (6-inch) spacing] and a length of 0.1 m (1/2-inch) stainless steel tubing were run to each filter in the prefilter station. Each prefilter station contained four in-line filters (supplied by Ratfisch Instrumente) and an air eductor mounted in a metal enclosure. Instrument air [515 KPa (60 lb/in^2 g)] was used to provide motive force to the air eductor. The suction created by the air eductor would draw the sample from the probe at a velocity of 0.002 m^3/s (5 stdft^3/min) through each filter in the prefilter station. The analyzer pump draws the sample at a rate of 5 l/min from the filter through the analyzer. A secondary filter (ceramic material of construction) is also provided in the oven detection unit of the analyzer to filter the sample a second time before it enters the oven detection unit.

These prefilter stations were mounted inside the dip and prime ovens. Therefore, the temperature of the prefilter stations was identical to the operating temperatures of the curing ovens.

The analyzer and prefilter stations were connected by heated sample lines. The heated sample lines were preassembled by the vendor to lengths specified by the project team, ranging from 3.05 to 9.14 m (10 to 30 feet) depending on the location of the sample point and control room. The heated sample lines were controlled at the same temperature as the analyzer's oven detection unit [121°C (250°F)] with a controller provided by the analyzer supplier. Each heated sample line included a 0.01 m (1/4-inch) Teflon® line and was electrically traced and insulated.

For sampling of solvent concentrations in the ductwork such as the inlet and discharge from the incinerator, a heated prefilter and a single tube, heated sample line were used. The heated prefilter was supplied by the analyzer vendor. It was electrically connected to a heated sample line. A uniform temperature was maintained using the analyzer temperature controller. The heated prefilter was mounted on the ductwork and the sample was drawn through the heated prefilter and heated sample line by the analyzer pump (See Appendix G).

The only exceptions to this sampling approach were monitoring of fume tunnel and ambient air streams. Since these streams were at room temperature, stainless steel lines were run to the analyzers. The analyzer ceramic prefilter was used to remove dust from the stream to prevent plugging inside the analyzer oven detection unit.

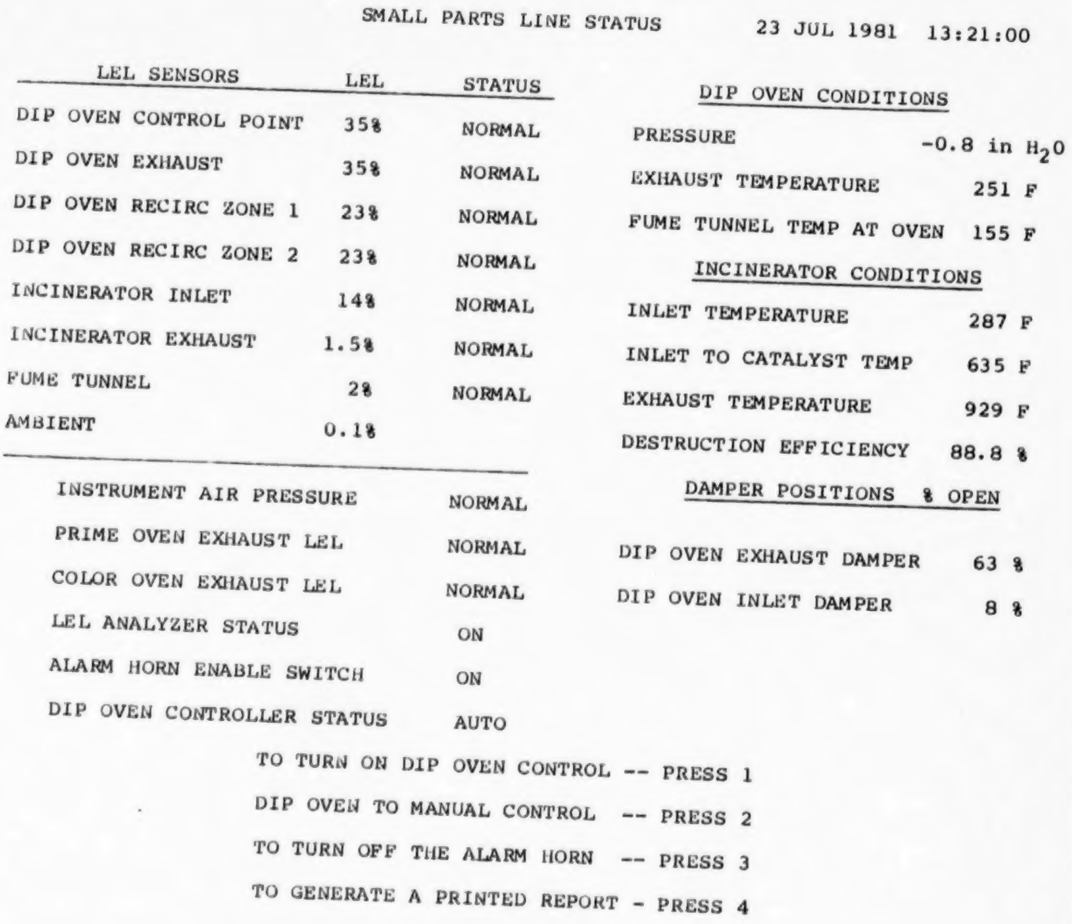
Examples of the complete layout of the heated prefilters, prefilter stations, and dampers are shown in Appendices E and F.

Displays and Reports

The displays for the prototype and reports were formatted to include information about the operation and to permit the generation of hard copy reports. The format for the CRT screens and for the printed report was designed by the project team and the software for generation of CRT displays and printed reports was completed prior to the installation of the microcomputer at Mack Trucks.

The format for the CRT display is shown in Figure 14. The operating status of the control system and readings from the sensors was included on one screen for operation. The numerical and status information displayed on the screen was automatically updated four times a second.

The format for the printed report is shown in Table 10. This report can be generated on command by pressing the "4" button on the keypad or automatically at a time period set by the microcomputer. A report is automatically generated if an alarm condition or malfunction occurs.



```
                         SMALL PARTS LINE STATUS        23 JUL 1981  13:21:00

      LEL SENSORS           LEL       STATUS
                                                        DIP OVEN CONDITIONS
DIP OVEN CONTROL POINT      35%       NORMAL
                                                  PRESSURE                   -0.8 in H2O
DIP OVEN EXHAUST            35%       NORMAL
                                                  EXHAUST TEMPERATURE          251 F
DIP OVEN RECIRC ZONE 1      23%       NORMAL
                                                  FUME TUNNEL TEMP AT OVEN     155 F
DIP OVEN RECIRC ZONE 2      23%       NORMAL
                                                       INCINERATOR CONDITIONS
INCINERATOR INLET           14%       NORMAL
                                                  INLET TEMPERATURE            287 F
INCINERATOR EXHAUST        1.5%       NORMAL
                                                  INLET TO CATALYST TEMP       635 F
FUME TUNNEL                  2%       NORMAL
                                                  EXHAUST TEMPERATURE          929 F
AMBIENT                    0.1%
                                                  DESTRUCTION EFFICIENCY      88.8 %

    INSTRUMENT AIR PRESSURE           NORMAL         DAMPER POSITIONS  % OPEN

    PRIME OVEN EXHAUST LEL            NORMAL      DIP OVEN EXHAUST DAMPER      63 %

    COLOR OVEN EXHAUST LEL            NORMAL      DIP OVEN INLET DAMPER         8 %

    LEL ANALYZER STATUS               ON

    ALARM HORN ENABLE SWITCH          ON

    DIP OVEN CONTROLLER STATUS        AUTO

                    TO TURN ON DIP OVEN CONTROL -- PRESS 1

                    DIP OVEN TO MANUAL CONTROL  -- PRESS 2

                    TO TURN OFF THE ALARM HORN  -- PRESS 3

                    TO GENERATE A PRINTED REPORT - PRESS 4
```

Figure 14. Microcomputer Screen Display Simulation values shown

TABLE 10. FORMAT OF PRINTED REPORT AT MACK TRUCKS

MACK TRUCKS

Data Log Sheet

For Time Period:____________________Date;______________________Time

	Average	Low	High
LEL Sensors			
Dip Oven Control Point	%	%	%
Dip Oven Exhaust	%	%	%
Dip Oven Recirculation, Zone 1	%	%	%
Dip Oven Recirculation, Zone 2	%	%	%
Incinerator Inlet	%	%	%
Incinerator Exhaust	%	%	%
Ambient	%	%	%
Dip Oven Conditions			
Pressure in H_2O	in.	in.	in.
Exhaust Temperature	°F	°F	°F
Fume Tunnel Temperature at Oven	°F	°F	°F
Controller On-line	%	%	%
Incinerator Conditions			
Inlet Temperature	°F	°F	°F
Inlet to Catalyst Temperature	°F	°F	°F
Exhaust Temperature	°F	°F	°F
Destruction Efficiency	%	%	%

Hydrogen Generator

Pure hydrogen is required as a fuel source for the hydrocarbon analyzer. The prototype system used a small generator that provided hydrogen at a rate up to 360 ml/m. The generator electrolytically converts deionized water to pure hydrogen and oxygen. The oxygen is vented; there is no appreciable volume of hydrogen stored at any time to cause concern for fire or explosion. A bottled cylinder of hydrogen could have been used in place of the generator, but a hydrogen generator was selected to eliminate the need to replace bottles.

Calibration Gas

A non-flammable bottled gas cylinder that is certified by the supplier to consist of a specified percent of the LEL level was used for calibration. The gas is usually a mixture of air and propane. The gas is used to calibrate the hydrocarbon analyzer for the range of solvent concentrations expected to be incurred. The mixture used at Mack Trucks was 3000 ppm propane in air.

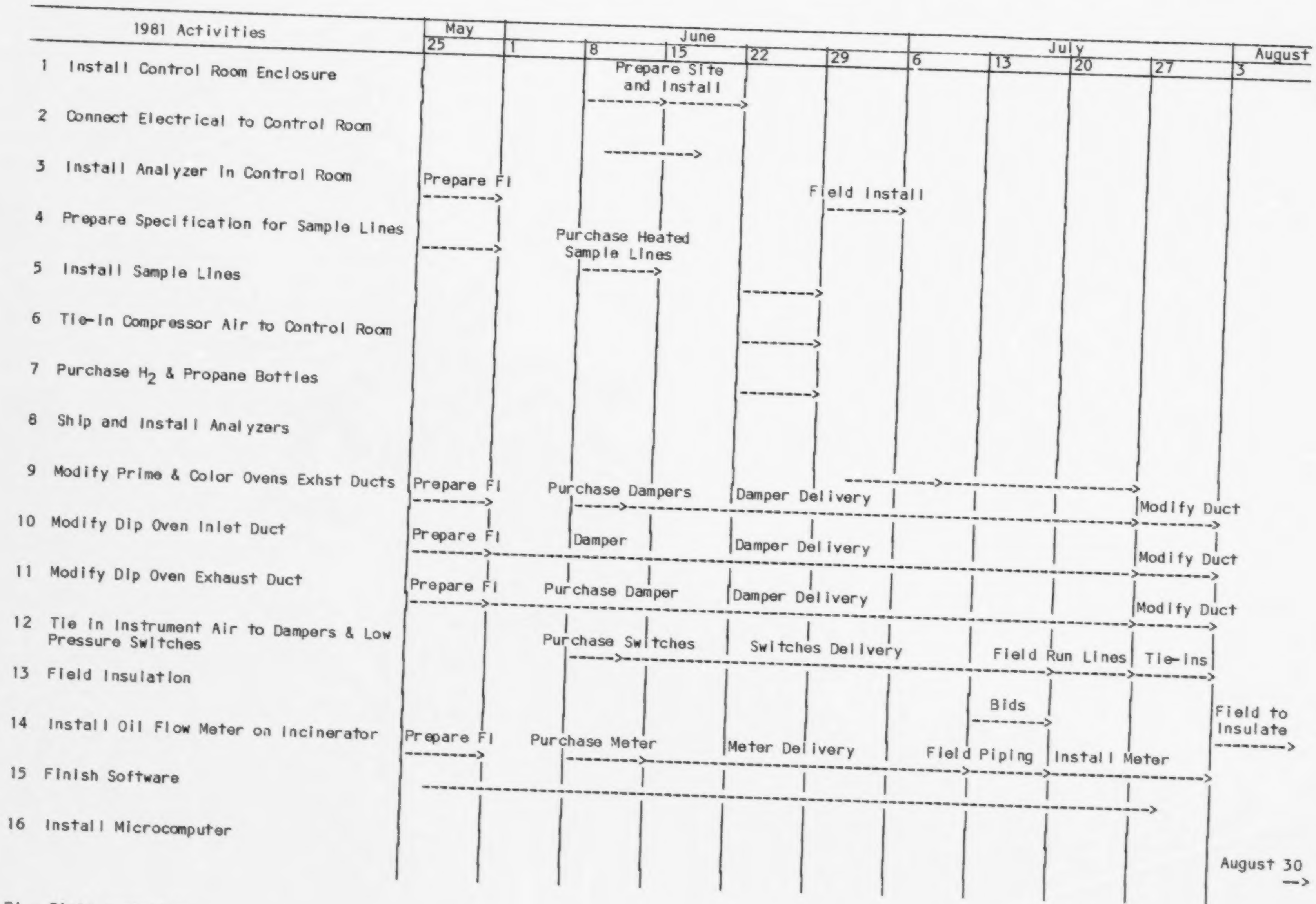
Utility Requirements

A 115-volt AC power supply and clean, dry oil-free instrument air were required. The utilities were run off existing Mack Trucks utility service lines. Existing air filters to supply breathing air to spray booth personnel were utilized to provide clean air to the analyzers.

SYSTEM INSTALLATION REQUIREMENTS AND SCHEDULE

The equipment requirements were presented in the previous section. The schedule for completion of the installation at Mack Trucks is shown in Figure 15. No down time occurred during system installation; sample probes, the ductwork modifications, and the microcomputer were completed during a scheduled plant shutdown.

During the installation, an operator training program was instituted. Since the software was developed before the microcomputer was delivered, the training took place using the same simulation runs used to test the control software. The operators and supervisory personnel were acquainted with the expected changes in performance when one or more of the process conditions changed. Likewise, the operator handbook (Appendices G and H) was prepared and provided the operators with a description of the technology and specifications for the major hardware and instrumentation.



FI = Field Installation

Figure 15. Major Retrofit Activities and Schedule (Mack Trucks)

Each control loop was checked and operated in conventional and controlled modes to identify potential problems. Debugging procedures were employed to eliminate any equipment or program defects. The system's response to changes in production capacity and solvent loading were checked off-line without direct digital control of the oven and incinerator's air and energy flow rates.

The system was brought on-line on October 1, 1981. Continuous coverage of the operation was provided to assist plant operators. A run was made to test the control system's reponse to changes in production and operating conditions. After this test, the system was adjusted and put into routine operation for long-term evaluation.

Software for Control System at Mack Trucks

The functions of the control system and equipment specific to the Mack Trucks' installation were described previously. The logic and software for the microcomputer control system are described in Appendix I.

PROTOTYPE TESTING AND RESULTS

Start-up

The initial check-out and start-up of the system began in September 1981. The following evaluations were completed:

- Air flow rates were measured using a velometer from the exhaust of the fume tunnel, prime, color and dip ovens. The self-regulating dampers were then set and air flow measurements were once again taken to assure that the rates were maintained at their previous values.

- After production runs were completed, the microcomputer control functions were initially checked out. The dip oven was run without coated parts and pressure control and damper action were checked. The mechanical stop was set on the dip oven exhaust damper to maintain a minimum of 0.47 m^3/s (1000 $stdft^3/min$) for the exhaust from the dip oven.

- The analyzers were started up and calibrated using the calibration gas. Several of the analyzers did not work due to mechanical problems with the FID burner. The spark mechanisms were broken and these were replaced. Following this corrective action, the analyzers functioned correctly.

- Electrical problems associated with poor connections were observed for two of the heated sample lines. The heated sample lines were operable after all the electrical connectors were checked out and repaired.

- Software Revisions - Minor software modifications were completed during the initial checkout period. The major change was to permit control of the ventilation air flow rate from the dip oven based on all analyzer point located in the dip oven instead of only the exhaust concentraton and inlet location. The reason for this change was the similarity of readings under the existing high ventilation air flow rates from the dip oven.

The following problems developed after the initial start-up period in October:

- Eductors for Prefilter Station - The capacity of the eductors worsened after the initial start-up. It was found that the suction rate was less than one-half of the specified air rate. New eductors were installed and the air flow rates met the specified 0.01 m^3/s (20 std ft^3/min).

- Analyzer pump vibration problems developed after 6 weeks of operation. The bracket for mounting four analyzer pumps was revised to include separate mounting for each pump. The new mounting corrected the vibration problems that caused the pumps to become loose.

- Hydrogen Generator - Problems were experienced with the hydrogen generator due to the peak hydrogen demand for the two analyzer units. The unit was rated for 300 ml/min at 411.617 kPa (45 lb/in^2g) while the peak demand was 360 ml/min. The vendor initially supplied the hydrogen generator electronic unit to handle the supply demand. At the peak demand, the unit automatically shut down due to thermal overload. The thermal overload switches were by-passed per the vendor recommendations and peak demand requirements were satisfied.

  Also, a number of times the unit was operated at low electrolyte levels, which caused boilover and some minor corrosion in the vent piping of the hydrogen. After each boilover, the hydrogen cell was flushed with deionized water and recharged with fresh electrolyte. This reestablished adequate hydrogen supply to meet the demand, and maintenance procedures were implemented to keep the electrolyte level at its recommended value.

- CRT - The tube in the CRT for the microcomputer failed after 5 months of service. The CRT was sent to the vendor and repaired. During this period, the air flow rates for the dip oven were maintained at the control point by using the analyzers as the back-up safety system. After repairs were made, the controller was put back into service.

Check-out of Safety Features

The control system included safety features to operate at solvent concentrations above 25 percent of the LEL. These safety features were based on the safety analysis and reviewed by NFPA prior to finalization of the design for Mack Trucks. For the Mack Trucks dip oven, the actions taken due to a malfunction in the system or due to solvent excursion above a control point of 35 percent of the LEL were to sound an alarm, automatically print conditions present at that time, and automatically open the inlet make-up air dampers and ventilation air damper. The major points of failure or malfunction and action designed for Mack Trucks follow:

- Solvent Excursion - If the system had been controlling at 35 percent of the LEL, the following action would be taken by the microcomputer:
    - At 45 percent of the LEL, a warning light is turned on; the status display of the CRT screen indicates "CAUTION."
    - At 50 percent of the LEL, with the warning light still on, an alarm sounds, a report is printed, the system returns to manual control, all dampers are opened and the conveyor can be stopped.
- Computer Malfunction - System is placed on manual control with all dampers open.
- Analyzer Malfunction - Computer opens all dampers and report is printed.
- Lack of Electricity - All dampers open automatically.
- Loss of Hydrogen or Air Flow Rates - By sensing hydrogen or air pressure, the computer automatically changes to manual control, all dampers open, warning light is turned on and alarm is sounded.

In order to check out the safety features of the control system, tests were conducted with the system operational in the automatic mode. These tests proved conclusively that all design safety features were operational and would react as designed.

Solvent excursions were simulated for each of the four points of sampling in the dip oven. The signal (0 to + 10 volts) from the analyzer to the microcomputer is directly proportional to the percent of the LEL. A voltage source using a precision voltage calibrator was used to give a signal equivalent to 35, 45, and 55 percent of the LEL to the microcomputer. Another test involved disconnecting a sample line from the prefilter station and placing it in a sample bottle of solvent. Each time the controller automatically responded with the required action to these tests.

To simulate microcomputer failure, the electricity in the microcomputer was disconnected after it was in automatic control. This resulted in an instantaneous change from automatic to manual control plus actions as previously stated.

Tests were repeated with the other equipment by disconnecting or shutting of electricity, analyzers, and utilities (air and hydrogen) for the analyzer. The required fail safe response was obtained in each case.

Final Operation and Results

The control system was first placed in complete operaton on October 1, 1981. When placed in automatic control, the ventilation air damper from the dip oven closed to its maximum position (mechanical stop). The inlet make-up air dampers located at the Zone 1 and Zone 2 recirculation fans fully closed. The minimum ventilation air flow rate was 0.47 m^3/s (1000 $stdft^3/min$).

At the conclusion of the first production run, the mechanical stop for the exhaust damper position was changed to reduce the minimum air flow rate to 0.24 m^3/s (500 $stdft^3/ min$). During the next production run, the controller performed in the same manner and the minimum ventilation air flow rate of 0.23 m^3/s (490 $stdft^3/min$) was obtained. Further reductions in the ventilation air flow rate were not attempted since this volume was determined to be the minimum rate necessary to maintain a slightly negative pressure in the dip oven.

Table 11 provides typical solvent profiles for the oven before retrofit and, for the oven under control after retrofit for a two-week production period.

The solvent concentrations at all locations were less than one percent of the LEL. For the dip oven, the uncontrolled solvent readings were considerably less than the expected value of 6 percent of the LEL in the exhaust. The air flow rates before placing the dip oven in automatic control were identical to the rates that Mack Trucks had measured before the retrofit was completed. However, the lower solvent flow concentrations were due primarily to lower production rates.

When the dip oven was operated under automatic control, the ventilation air flow rate was always maintained at 0.23 m^3/s

(490 stdft^3/min). The solvent concentrations inside the oven varied with production rate and frequency at which the parts were place on the conveyor. Parts are removed regularly from the conveyor without replacement which eliminates solvent from entering the oven. The result of these operating practices, therefore, reduced the average solvent concentration.

Since the ventilation air flow rate was always maintained at the minimum rate, the solvent profile became dependent on the rate at which the parts were cured. When the coated parts entered the oven, the solvent concentration would gradually increase to a maximum level. Once placed in automatic control, however, the minimum air flow rate was always held constant; therefore, the energy savings for the curing oven were constant based on the reduction in ventilation air flow rate of 1.37 m^3/s (2910 stdft^3/min) [1.6 to 0.25 m^3/s (3400 to 490 stdft^3/min)]. When parts are recovered from the conveyor, the oven is still maintained at curing conditions. Since no parts are being cured, the solvent concentration reduces until normal production is resumed. It was not possible to estimate the solvent rate accurately because no correlation existed for the amount of paint applied to each part or the actual utilization of the oven during this time.

The maximum controlled solvent concentrations during the production period are also shown in Table 11. The exhaust solvent concentration was lower than at any sampling point in the dip oven. The highest concentration was located in Zone 1, which becomes the control point where production rates are high enough to reach the controller set point of 35 percent of the LEL. The solvent concentration of 35 percent of the LEL could have been reached if the ventilation air flow rate could have been reduced to 0.08 m^3/s (170 stdft^3/min) [(12 percent of the LEL/35 percent of the LEL) x 490 stdft^3/min] however, this was not possible because the system also had to be controlled based on maintaining a slightly negative pressure in the dip control.

The most important result of the solvent profile studies was that the highest exhaust concentration was 40 percent lower than the highest concentration in Zone 1 of the dip oven. If the exhaust concentration had reached 35 percent of the LEL and the exhaust location had been the only control point, it would have been possible for the concentration in Zone 1 to exceed 60 percent of the LEL--a potentially dangerous condition, one which is not permitted under the NFPA Codes. Therefore, the need to provide multiple sampling points and to control based on the highest reading was proven to be the correct design for this system.

The fume tunnel exhaust solvent concentration also increased from 1 percent of the LEL to 3 percent of the LEL. The

TABLE 11. RETROFIT EFFECT ON SOLVENT CONCENTRATIONS

Sample Probe Location	Avg Solvent Concentration, % of LEL October 5-16 Manual Control	Avg Solvent Concentration, % of LEL Oct 26-Nov 6 Automatic Control	Max Solvent Concentration, % of LEL; Oct 26-Nov 6 Automatic Control1/
Dip Oven Entry	< 1.0	4.0	8.0
Dip Oven Exhaust	< 1.0	3.0	7.0
Dip Oven Zone 1 Recirc	< 1.0	5.0	12.0
Dip Oven Zone 2 Recirc	< 1.0	4.0	7.0
Incinerator Inlet	< 1.0	1.0	2.0
Incinerator Exhaust	< 1.0	< 1.0	< 1.0
Fume Tunnel Exhaust	1.0	3.0	4.0

1/ Average solvent concentrations achieved ater the retrofit were considerably lower than the maximum solvent concentrations during the operation test period due to the following:

a. Production oven start-up with no parts coating
b. Production personnel breaks
c. Variability of production rates.

Data provided by Mack Trucks

fume tunnel was connected directly to the dip oven with the exhaust duct for the fume tunnel located at the entry. Although the fume tunnel ventilation rate remained fixed under controlled conditions, the amount of air taken from the fume tunnel at the entry to the dip oven was reduced under automatic control. Therefore, the solvent concentration increased to the point where the parts left the fume tunnel and entered the curing oven.

A summary of the documented fuel savings and average conditions during automatic control are shown in Table 12. The fuel consumption for the dip oven was reduced by 56 percent, meeting the original projection of air flow rate reduction and fuel savings.

The documented fuel saving for the catalytic incinerator was 13 percent. This reduction is lower than the calculated savings of 30 percent based on the air flow rate reduction. The reason for this difference was the problem with the existing incinerator temperature controller. The fuel rate and exhaust temperature for the incinerator cycled below the set point of 343°C (650°F) (catalyst reactivity temperature). This reduced the fuel savings achievable by control since the temperature rise of the combined air stream for the three ovens and fume tunnel was lower than expected rates.

The destruction efficiency was determined by continuous measurement of the solvent concentrations at the inlet and discharge of the catalytic incinerator. The destruction efficiency was in the range of 70 to 94 percent. The variability in the destruction efficiency was the result of incinerator temperature cycling below the set point temperature.

The incinerator is controlled by sensing the inlet temperature to the catalyst bed and adjusting the fuel oil rate to the incinerator burner. This temperature should be maintained constant at approximately 343°C (650°F), which is the catalyst reactivity temperature. However, it cycled with the incinerator controller between 302°C and 385°C (575°F and 725°F). The solvent concentration at the discharge of the catalytic incinerator was usually less than 1 percent of the LEL, a low enough value to meet Mack Trucks' emission control requirement.

A change in the temperature control point to maintain exhaust temperature in the range of 538 to 593°C (1000 to 1100°F) would reduce the variability of the destruction efficiency. However, additional fuel oil would be consumed and catalyst life would be decreased if the control temperature was raised to 482°C (900°F). Also, no benefit in terms of final solvent emission would result since the exhaust concentration was low enough to meet regulations.

TABLE 12. MACK TRUCKS CURING LINE CONDITIONS

Manual and Automatic Operation

OPERATING CONDITIONS	Oct 5-16 Manual Operation	Oct 26-Nov 6 Automatic Operation
Dip Oven		
Air Flow, stdft^3/min	3400	490
Exhaust Temp, °F	252	282
Avg Exhaust Solvent Conc, % LEL	< 1.0	3.0
Fuel Consumption, MM Btu, hr[1]	1.74	0.77
Prime Oven		
Air Flow, stdft^3/min	2000	2000
Exhaust Temp, °F	250	250
Avg Exhaust Solvent Conc, % LEL	< 1.0	< 1.0
Color Oven		
Air Flow, stdft^3/min	2000	2000
Exhaust Temp, °F	250	250
Avg Exhaust Solvent Conc, % LEL	< 1.0	< 1.0
Auxiliary Fume Tunnel		
Air Flow, stdft^3/min	1840	1840
Exhaust Temp, °F	70	70
Avg Exhaust Solvent Conc, % LEL	1.0	3.0
Catalytic Incinerator		
Total Air Flow, stdft^3/min	9240	6330
Inlet Temp, °F	257	281
Exhaust Temp, °F	787	828
Destruction Efficiency, %	84.5	93.6
Fuel Consumption, MM Btu/hr	4.72	4.16
Fuel Consumption in Dip Oven & Incinerator, MM Btu/hr	6.46	4.93
Fuel Reduction in Dip Oven & Incinerator, MM Btu/hr		1.53
Fuel Cost Saving in Dip Oven & Incinerator, $/yr[1]	22,800	

[1] Assumes $6.98/MM Btu fuel oil cost, 9 hrs/da, 237 da/yr.

A controlled test to evaluate the benefits of reduced air flow rates or destruction efficiency was made during an 8-hour production run. The incineration temperature was manually controlled to maintain a constant value. The destruction efficiency was 84 percent on manual control with maximum air flow rate for the dip oven. The destruction efficiency improved to 94 percent with the dip oven under control at an air flow rate of 0.25 m^3/s (490 $stdft^3/min$) (Refer Table 12).

Since the destruction efficiency can be monitored continuously by the control system, it is possible to make temperature adjustments to the incinerator to reach a desired destruction efficiency. Also, the control system can be designed to provide supervisory control over the incinerator, which would automatically maintain the desired destruction efficiency by automatically controlling the incinerator temperature based on destruction efficiency. This feature, however, was not implemented at Mack Trucks due to their concern over the operation of the air /air heat exchanger that provides heat to the E-coat oven.

The results of the operational evaluations of the control systems indicated that the product quality of the coated brackets and other truck parts cured in the dip oven was not changed due to the actions of the control system to reduce air flow rates.

The operation of the curing line and incinerator did not change appreciably after the control system was placed in operation. The curing oven(s) and incinerator were started up after modification and operated without changing the existing operator procedures. Once the line was in operation, the dip oven was placed into automatic control by pressing a single command button on the keypad.

Operator interface with the system is to check operating status periodically on the control system shown on the CRT, respond to audible or visual caution warnings or alarms, and calibrate the analyzers before start-up of the curing line.

In summary, most of the original objectives for the project were achieved at Mack Trucks. Ventilation air flow rates were reduced to the maximum level possible for the modified oven operating under automatic control. The annual energy savings projection of $26,000 was not reached based on the oven and incinerator operating on one-shift production period. The savings were determined to be $22,800. The savings were lower because of the temperature control of the catalytic incinerator. This however equates to a minimum of $67,000 per year when the system is operating over a three-shift basis at full production. Even greater savings can be projected for higher solvent loadings in the oven. Product quality was not affected. All control and safety functions using the microcomputer were successfully implemented and put into operation without affecting production. The highest solvent concentration reached was approximately 12 percent of the LEL, which was below the original control objective of 35 percent of the LEL due to lower than expected production rates.

SECTION 5

POTENTIAL FOR TRANSFER OF TECHNOLOGY

INTRODUCTION

The application of a microcomputer control system for continuous conveyor type curing oven was demonstrated at Mack Trucks. The transfer of this technology to other sectors of the coating industry would incorporate the same basic design features but would require tailoring to site-specific requirements of each industrial sector and each curing oven and incinerator. This section highlights the major benefits of the microcomputer control system and major design criteria that should be addressed. Cost savings projections for incinerator and curing ovens are presented so that preliminary evaluations by industry could be completed in order to project economics for institution of a project leading to the installation of a control system.

The following summary of benefits would be applicable to most continuous curing ovens and for plants using incinerators for VOC emission control:

- Safety - Provides continuous monitoring and control of solvent concentrations inside curing ovens with fail-safe features to reduce prospects of fires or explosions caused by solvent excursions or high solvent concentrations.
- Curing Oven Fuel Savings - Provides control of the ventilation air flow rate(s) at a minimum level depending on solvent loadings and pressure resulting in direct fuel savings for the curing oven.
- Incinerator Fuel Savings - Reduces volume of air required for incineration and increases concentration of solvent thereby reducing fuel demand.
- Incinerator Destruction Efficiency - Provides continuous monitoring of the destruction efficiency for incinerators, which would assure compliance with regulations and could result in fuel savings if a higher than necessary destruction efficiency is being used prior to system installation.
- Emission Control Investment - Reducing air flow rates by controlling curing ovens would reduce investment costs for VOC emission control equipment.

A control system can be configured to meet most site-specific requirements, which would include the following control and monitoring functions:

- The solvent concentrations should be measured continuously in each zone of a curing oven and, in some cases, at multiple points in a zone where high solvent concentrations could occur.
- The ventilation air flow rates would be controlled automatically based on the highest solvent concentration reading(s) and/or pressure in the curing oven.
- Dampers equipped with actuators and I/P convertors would be installed for each air intake and exhaust duct in the curing oven to provide control of incoming and ventilation air flow rates.
- Sample handling for the hydrocarbon analyzer(s) should include filters and heated sample line(s) to eliminate sample line pluggage to the hydrocarbon analyzer(s).
- The system should include fail-safe design based on NFPA Codes and any other applicable codes.

SAFETY

The NFPA Codes have established the guidelines for design and operation of curing ovens and incinerators with continuous monitoring systems. The ventilation air flow rates must be maintained and controlled to prevent the solvent concentration from exceeding 50 percent of the LEL in a controlled oven. For the ovens without continuous monitoring control, the solvent concentrations must be maintained below 25 percent of the LEL in the oven. Even at high ventilation air flow rates, where exhaust concentrations are below 25 percent of the LEL, fires or explosions have occurred in the coating industry.

The features of the microcomputer-controlled oven can reduce the possibility of fires and explosions. In the event of a solvent excursion above 50 percent of the LEL, the controller could automatically increase ventilation air flow rate to a maximum, shut-off burners to the oven, stop work from entering the oven, and sound an alarm.

Beyond the above provisions, the microcomputer also can provide on-line checks of analyzers and monitors for the utility service supply (air and fuel for analyzers) for analyzers and damper systems. In the event utility supply is lost or reaches a caution level, the microcomputer would automatically increase ventilation air flow rates.

In addition to these safety design features, the microcomputer would maintain a negative pressure in the oven. By sensing pressure in each zone, particularly the entry and exit of an oven, the ventilation and incoming air flow rates are adjusted by damper control to prevent hot air from escaping to the working environment.

ESTIMATION OF CURING OVEN FUEL SAVINGS

A reduction in the ventilation air flow rate reduces the fuel demand for curing ovens. As discussed in Section 4, the minimum ventilation air flow rate is dependent on solvent loading, pressure, and combustion air rates. Once the minimum rate is established, then the fuel savings can be accurately projected. The fuel demand for curing the parts and for radiation losses will remain constant with and without a control system.

The air heating requirements for curing ovens are directly proportional to the ventilation air flow rate and average temperature of the ventilation air. Figure 2, Section 4, provides an approximation of this fuel demand and annual fuel costs for curing oven air heating as a function of the exhaust temperature based on heating 4.72 m^3/s (10,000 $stdft^3/min$) of ventilation air.

Estimates of the fuel demand for any other ventilation air flow rate can be calculated based on the following formulas:

Formula 1. $FDP = \dfrac{(FDF \text{ x } VP)}{4.72\ m^3/s}$

FDP = Fuel demand of plant at actual ventilation air flow rate
FDF = Fuel demand based on Figure 2
VP = Current ventilation air flow rate
4.72 m^3/Sec = 10,000 $Stdft^3/m$

The estimate of fuel demand using the control system would be based on the existing ventilation air flow rate and average solvent concentration in the ventilation air. The formulas follow:

Formula 2. $VPC = \dfrac{(VP \text{ x } SE)}{SC}$

VPC = Ventilation air flow rate with control
SE = Existing solvent concentration in exhaust
SC = Controlled solvent concentration

Formula 3. $FDC = \dfrac{(FDP \text{ x } VPC)}{VP}$

FDC = Fuel demand with control
FDP = Refer Formula 1
VPP = Refer Formula 2
VP = Refer Formula 1

An estimate of percentage fuel savings is easily calculated for air heating demand based on the measurement of the existing curing oven average solvent concentration, and the expected solvent concentration once a control system is installed. The following formula can be used for this estimation:

Formula 4. $$\%\ \text{Fuel Savings} = \frac{(SC - SE)}{SC} \times 100$$

For example, if the existing concentration (SE) is 10 percent of the LEL and the controlled concentration (SC) is 30 percent of the LEL, the fuel saving is 67 percent.

METAL PRODUCTS INDUSTRY FUEL SAVINGS FOR INCINERATION AND CURING

An estimate of the total energy savings potential was completed for the miscellaneous metal products coating industry. Product lines in the miscellaneous metal products coating industry include office furniture, major and small appliances, industrial cabinets and partitions, toys, kitchen utensils, lawn furniture, and other small metal parts used for various end products. If the control technology is installed at 600 plants, the potential annual energy savings achievable would be equivalent to about 1.4 million barrels of oil. If each of these applicable ovens in this industry had an incinerator installed for VOC control with a microcomputer, annual energy savings would increase to the equivalent of a minimum 7.2 million barrels of oil. Figure 16 shows annual energy consumption estimates for the applicable ovens and incinerators in the miscellaneous metal products coating industry using the assumption shown in Table 13. In addition, the potential fuel value of the evaporated solvents is shown which assumes that the 600 ovens are each removing 0.09 m^3/hr (25 gal/hr) of solvent.

PROJECTION OF ENERGY SAVINGS FOR COATING INDUSTRY

An estimate of the potential for reducing fuel demand for curing ovens and incinerators for the coating industry was completed for a range of solvent removal rates. The conditions and bases selected by the project team to make the evaluation are shown in Table 14. The oven/incinerator computer model was used to determine the energy costs for an existing oven operating with an average solvent concentration of 7 percent of the LEL and with controlled oven operating at 35 percent of the LEL.

The solvent removal rates were based on the survey conducted during the project which included the miscellaneous metal products, coil coating, and fabric/paper coating industries. The solvent removal rate from ovens in the miscellaneous metal products industry were found to be in the range of 0.1 to 0.08 m^3/hr (2 to 20 gal/hr). In the fabric and paper coating industry, rates typically were found to be in range of 0.08 to

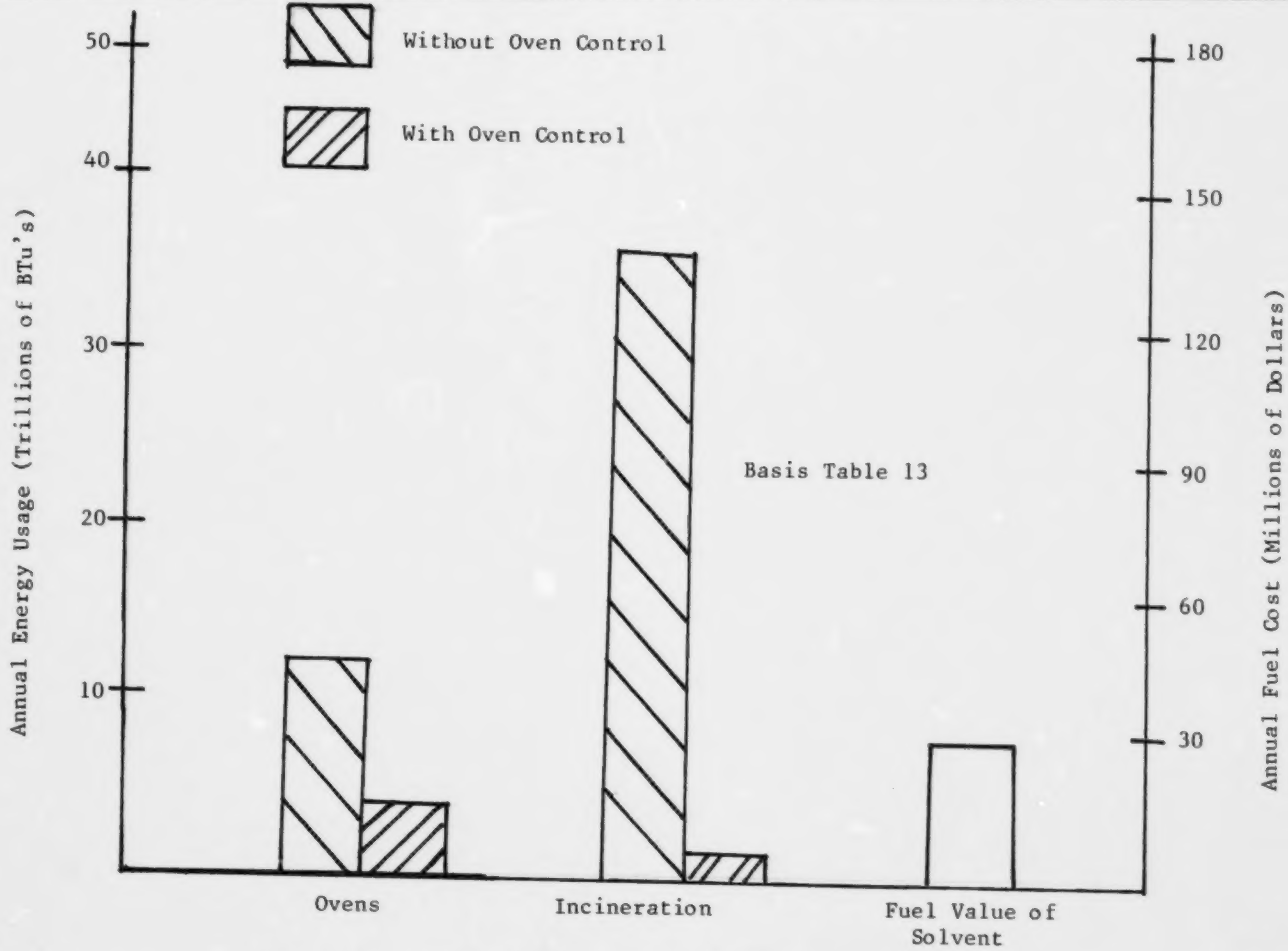


Figure 16. Energy Usage and Cost Estimate For The Miscellaneous Metal Products Industry

TABLE 13. BASES FOR ESTIMATES,

Figure 16

1. Six Hundred Applicable Ovens

2. Solvent Removal Rate: 25 gallons per hour

3. Percent of the LEL

   (a) Existing: 7 percent (0.03 to 25 percent range)
   (b) Controlled: 35 percent

4. Oven Exhaust Temperature: 350°F (150-700°F range)

5. Annual Operating Hours: 4,000 (2,000-7,500 hours range)

6. Fuel Cost: $3.80 per million Btu

7. Thermal Incinerator Exhaust Temperature: 1400°F (800-1500°F range)

8. Thermal Incinerator without Heat Recovery

TABLE 14. BASES FOR INDUSTRIAL CHARACTERIZATION

Oven Operating Conditions:

1. Solvent is toluene (7 percent of LEL existing concentration)
2. 350°F oven exhaust temperature
3. 60°F oven inlet temperature
4. 4000 hours annual operation
5. \$3.80/MM Btu natural gas cost
6. No radiant heat loss or product/conveyor heat load

Incinerator Operating Conditions:

1. Thermal incinerator
2. 1400°F incinerator exhaust temperature
3. 97 percent VOC destruction efficiency
4. No radiant heat loss

Waste Heat Boiler Operating Conditions:

1. 350°F exhaust temperature
2. 40 psig steam generated

0.14 m^3/hr (20 to 35 gal/hr). The coil coating industry's rates would be in the range of 0.14 to 0.28 m^3/hr (35 to 75 gal/hr).

Figure 17 presents the hourly fuel demand and annual energy costs for operating curing ovens over a range of solvent removal rates without incineration. If the solvent rate is assumed to be 0.09 m^3/hr (25 gal/hr) and the solvent concentration in the ventilation air is increased from 7 percent of the LEL to 35 percent of the LEL under control, the annual energy costs would be decreased from $75,000 to $20,000. This represents a reduction of 77 percent in both energy usage and annual energy costs for heating ventilation air.

As VOC regulations are promulgated, however, many coating oven operations may install incinerators to control solvent (VOC) emissions. The use of the microcomputer controller can, as shown at Mack Trucks, result in a significant reduction in energy cost for the operation of such oven/incinerator combinations by permitting the solvent concentration to be increased thereby reducing the ventilation air heating requirements for the system. Figure 18 illustrates the possible savings for a typical oven/thermal incinerator system operating at 7 percent of the LEL without control and operating at 35 percent of the LEL with control. A 94-percent reduction in energy usage and annual energy costs is possible for ovens with similar operating conditions.

The use of heat recovery with an incinerator to control VOC emission is justified in many cases. A primary heat recovery exchanger can be employed to reduced fuel demand for incineration by preheating the air from the curing oven before it enters the incinerator. Secondary heat recovery is another approach, which again recovers the energy from the incinerator exhaust gas to provide heat to a curing oven or to generate steam. Therefore, the analysis shown in Figure 18 is indicative of the maximum fuel costs and potential savings since incinerator fuel costs can be significantly reduced by installing heat recovery equipment while controlling the ventilation rates with the microprocessor.

INCINERATOR DESTRUCTION EFFICIENCY

The computer control system can provide a means to determine the destruction efficiency of the VOC emission control equipment. This would require the installation of analyzers to measure the inlet and exhaust solvent concentration.

The destruction efficiency for catalytic and thermal incinerators is based on residence time and temperature. Without continuous monitoring of the incinerator destruction efficiency, an incinerator is typically operated at a

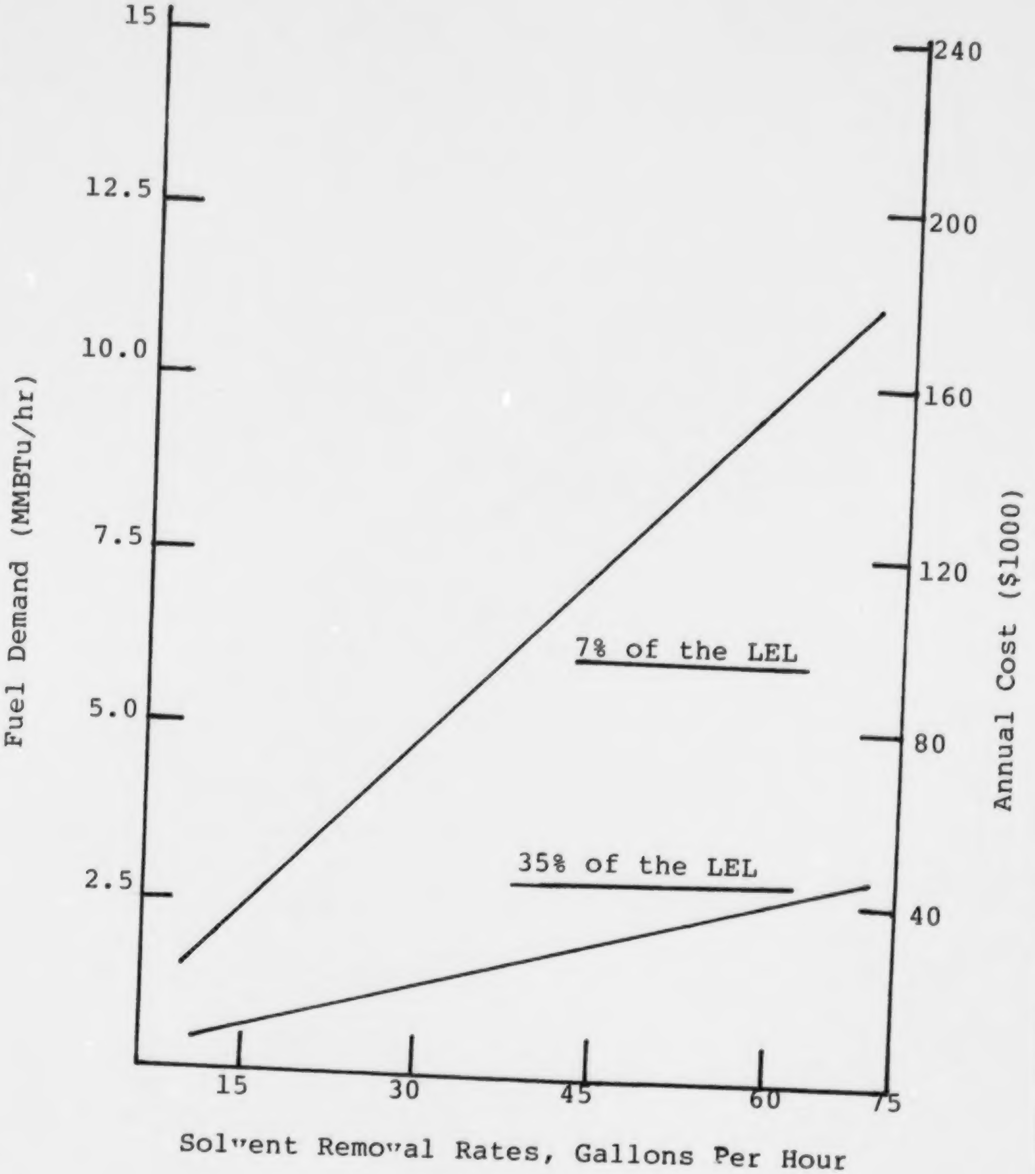


Figure 17. Energy Demand and Cost For Curing Ovens As Function of Solvent Loading

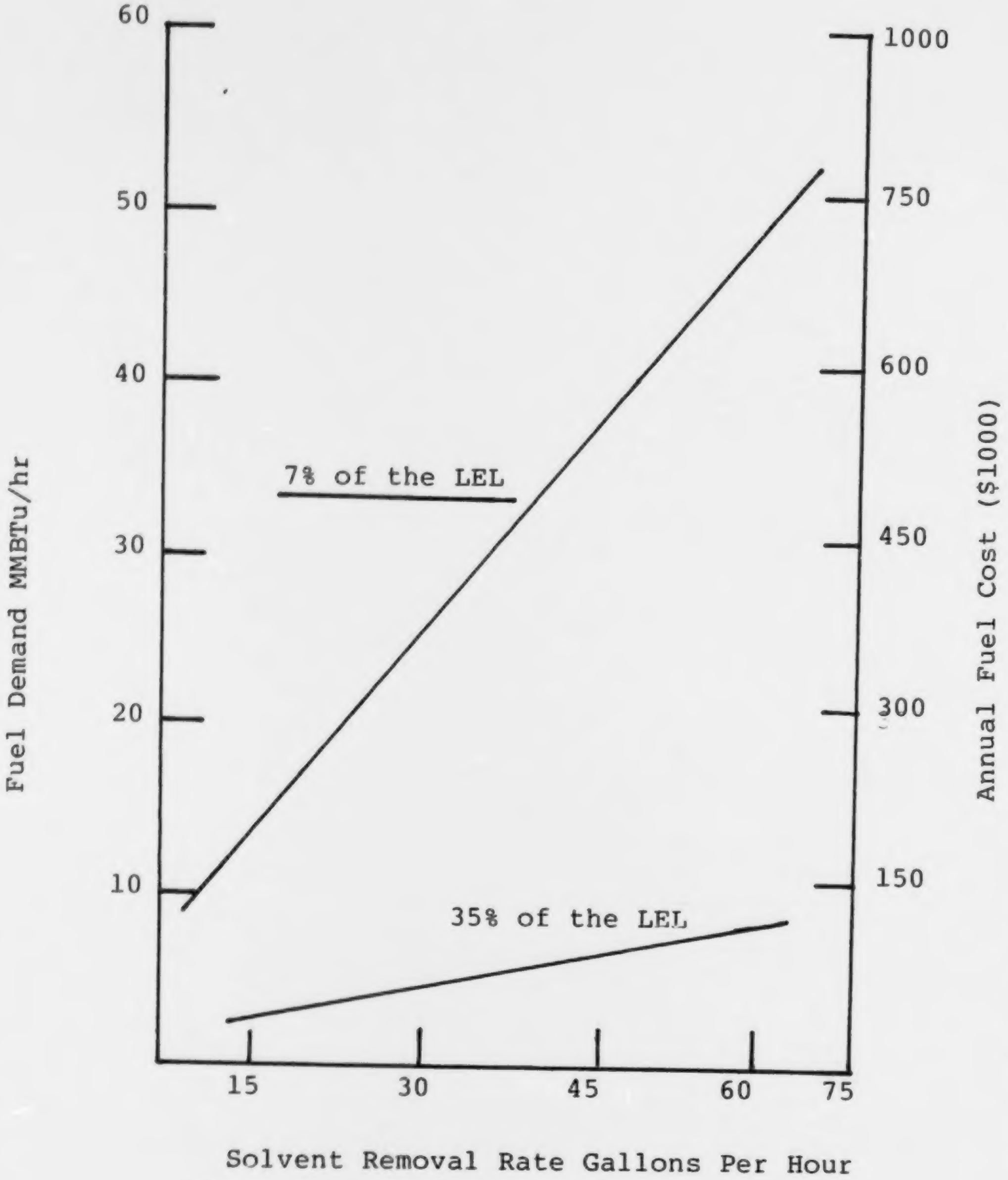


Figure 18. Energy Usage and Cost for an Oven With Thermal Incinerator No Heat Recovery

temperature specified by the supplier or, in some cases, environmental agencies.

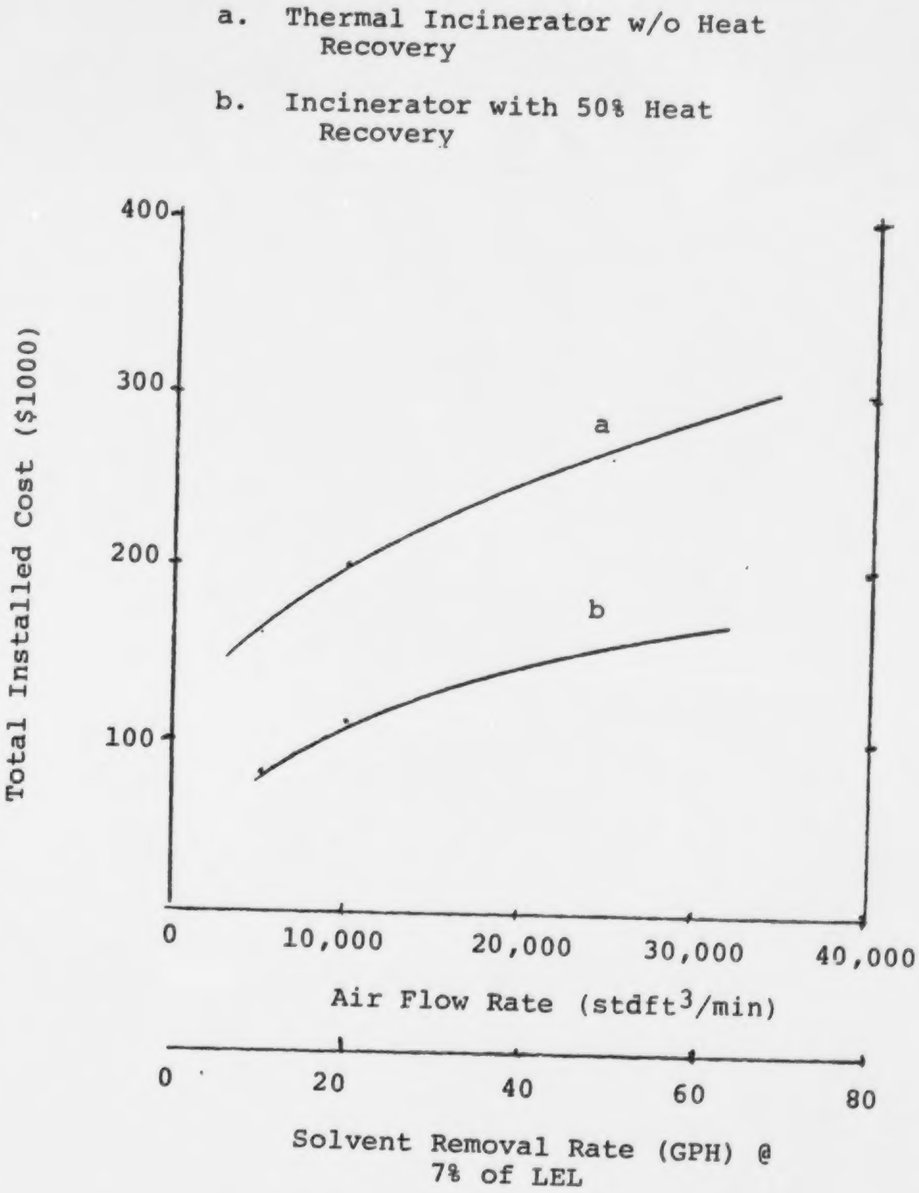
With continuous monitoring of the destruction efficiency of the incinerator, the required pollution reduction can be maintained at all times by optimizing the operation of the incinerator by microprocessor. This would assure that the regulations are being met at all times. In addition, fuel savings can be achieved if the operating temperature is set higher than required to meet the destruction efficiency. Fuel savings of 127 million Joules/hr to 169 million Joules/hr (120,000 to 160,000 Btu/h) are possible by reducing incinerator operating temperature by 37.8°C (100°F) for each 0.47 m^3/s (1000 $stdft^3/min$) of curing oven air being incinerated.

Investment Costs for Incineration

Another benefit of the control system is a reduction in the investment costs for incinerators and heat recovery systems. The investment cost for equipment is directly proportional to the curing oven air flow rates. Figure 19 shows the investment costs for thermal incinerator and a waste heat boiler as a function of air flow rates and solvent removal rates for maintaining an average solvent concentration of 7 percent of the LEL.

As previously discussed, the quantity of ventilation air is much greater at 7 percent of the LEL than at 35 percent of the LEL. The size of the incinerator and boiler will be smaller if the ventilation air flow rate is reduced with a microcomputer-controlled oven system. The ventilation air flow rate is approximately 80 percent lower when the solvent concentraion is controlled at 35 percent of the LEL. The total installed investment is estimated by assuming the installation and hardware costs are equal. The total installed cost should, therefore, represent a conservative estimate.

Referring to Figure 19, the total installed investment for a thermal incinerator with a waste heat boiler with an oven operating at 7 percent of the LEL and a solvent rate of 0.16 m^3/hr (40 gal/h) [9.42 m^3/s (20,000 $stdft^3/min$)] is approximately $250,000. For a microcomputer-controlled oven system controlling at 35 percent of LEL from 7 percent of the LEL and with a 0.09 m^3/hr (25 gal/h) solvent removal rate, the ventilation airflow could be reduced from the 9.44 m^3/s (20,000 $stdft^3/min$) to 2 m^3/s (4000 $stdft^3/min$). At this air flow rate, the total installed investment is approximately $150,000, a 40-percent savings. A similar approach can be used to find the savings involved when comparing the installed costs of the thermal incinerators without heat recovery at the two conditions previously discussed.



Source - Equipment vendor quotes, 1980

Figure 19. Investment Costs For Thermal Incinerator and Heat Recovery Auxiliaries

ECONOMICS FOR MICROCOMPUTER-CONTROLLED SYSTEMS

The economics for installing the control system based on prototype design were completed for a multizone curing oven with and without a thermal incinerator in place. For this evaluation, it was assumed that the thermal incinerator would not have heat recovery equipment. The energy savings projections were based on controlling the curing oven at 35 percent of the LEL from an initial concentration of 7 percent of the LEL for a range of solvent loadings typically encountered in the coating industry. The bases for the economic evaluation are shown in Table 15.

The estimate of the total installed investment for the control system for the two cases evaluated is shown in Table 16. It is assumed that the control system is installed on a continuous multizone curing oven. The oven has two exhaust ducts and two make-up air ducts. Destruction efficiency of the incinerator is continuously monitored. The actual installation costs for any plant would be highly dependent on the retrofit requirements and design of the oven.

The after-tax paybacks and discounted cash flow rates of return for a range of solvent removal rates are shown in Figures 20 and 21. Referring to Figure 20, for example, the after-tax payback is approximately two years for controlling a curing oven presently operating with a 0.11 m^3/hr (30 gal/h) solvent removal rate and 7 percent of the LEL. If a thermal incinerator is installed on the same oven without heat recovery, the after-tax payback is approximately 0.7 years.

The actual economics for a specific installation are dependent on the hours of operation, fuel costs, oven exhaust temperature, and total ventilation air flow rate reduction. For the installation of the control system on a curing oven without incineration, any decrease in the value of those conditions would lower the economic return. Likewise, if a thermal incinerator with heat recovery is already in place, the energy saving is lower. Therefore, a site evaluation of all of these factors must be made before installing a control system.

TABLE 15. BASES FOR ECONOMIC ANALYSIS

1. Depreciation - 10 year straight line
2. Investment Tax Credit - 20 percent
3. Escalation Rate of Fuel - 10 percent per year
4. Maintenance - 2 percent of TII; escalated at 10 percent per year
5. Taxes & Insurance - 2 percent of TII; escalated at 10 percent per year
6. Corporate Tax Rate - 46 percent
7. Operating Labor - $1000; escalated at 10 percent per year
8. Raw Material Costs - $1000; escalated at 10 percent per year
9. No Borrowed Capital
10. Fuel Cost - $3.80/million Btu
11. Hours of Operation - 6,000 hours annually
12. Microcomputer Controller Cost Estimate - Refer Table 16

TABLE 16. ESTIMATED EQUIPMENT AND INSTALLATION COSTS FOR CONTROLLER

(1981 Basis)

Major Equipment Hardware Cost	Curing Oven No Incinerator		Curing Oven Wi/Incinerator	
Temperature Sensors	$ 2,400	(5)	$ 3,800	(8)
Damper Assembly	19,300	(4)	24,000	(5)
Hydrogen Generator	3,000	(1)	3,600	(1)
Analyzers	36,000	(4)	52,000	(6)
Prefilter Station	9,700	(1)	9,700	(1)
Heated Prefilter	-		4,500	(2)
Microcomputer	27,000	(1)	35,000	(1)
CRT/Printer	3,500	(1)	3,500	(1)
Pressure Sensors	2,800	(2)	4,100	(3)
Heated Sample Lines	2,700	(4)	4,400	(6)
Electrical Wiring	1,500		2,000	
Control Room	6,000	(1)	6,000	(1)
Miscellaneous Fittings	1,000		1,500	
Sub-Total	$114,900		$154,100	
Site Services				
Installation Cost	15,500	(10%)	23,000	(15%)
Site Evaluation Engineering	5,800	(5%)	15,400	(10%)
Engineering Services	17,000	(15%)	30,800	(20%)
TOTAL INSTALLED INVESTMENT COST	$152,700		$223,300	

- o Number in parenthesis indicates number required
- o Costs based on vendor quotations (1981) and additional cost for auxiliary equipment
- o Site services taken as percent of total hardware costs
- o Curing oven two zone
- o Thermal incinerator with destruction efficiency monitor installed

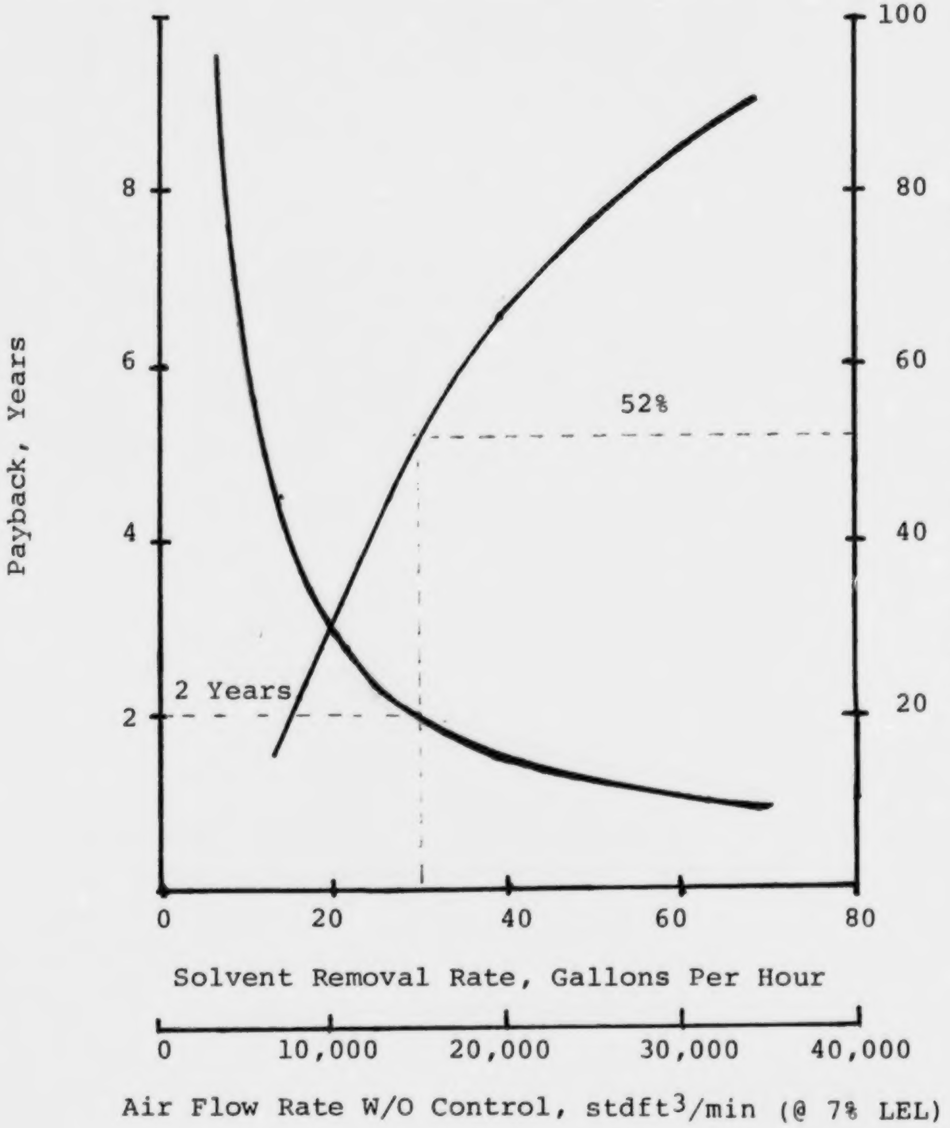


Figure 20. Economics For Computer Controlled Oven No Incinerator (Operating at 35% of the LEL)

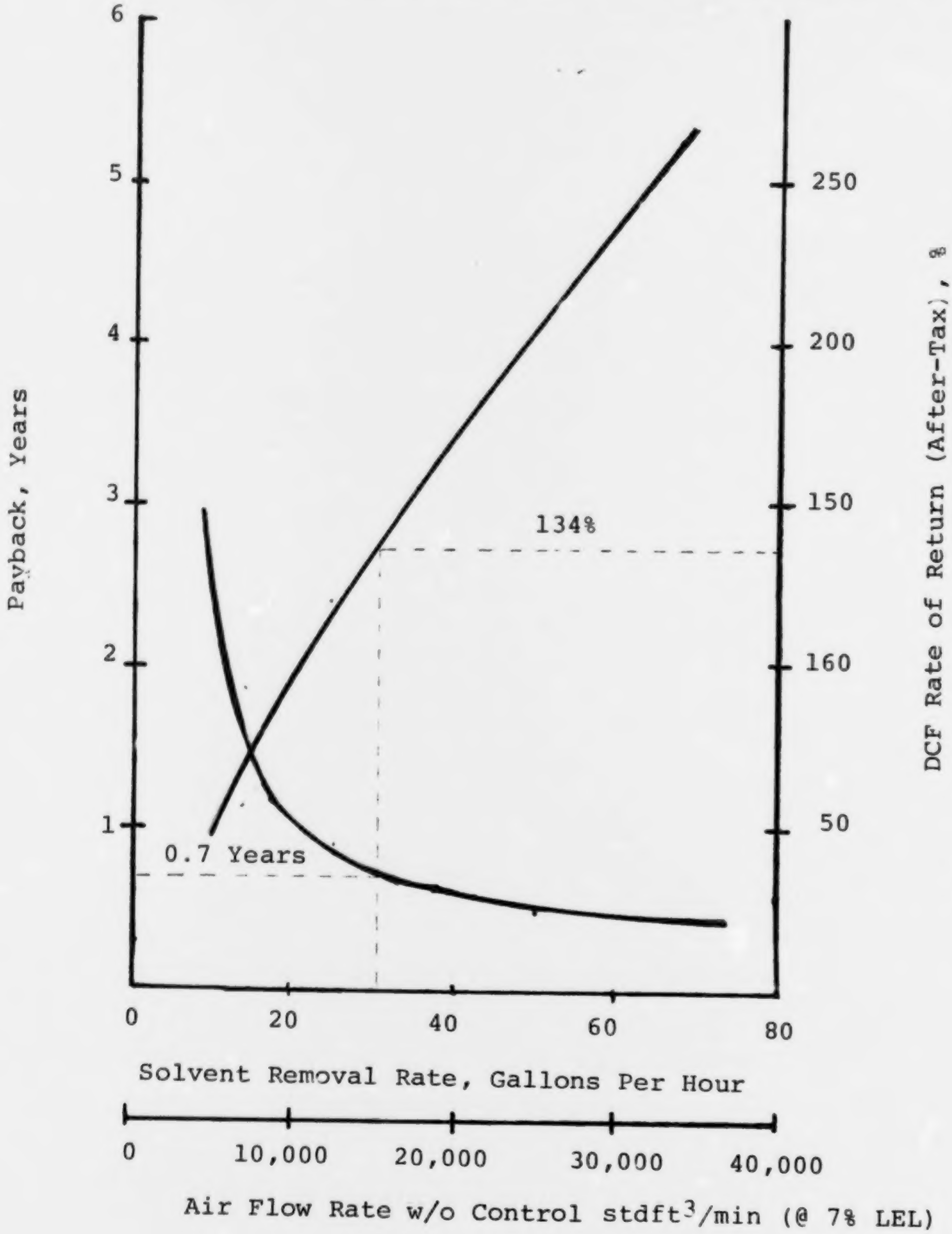


Figure 21. Economics of Computer Controlled Oven and Thermal Incinerator No Heat Recovery (Controlled at 35% of the LEL)

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APPENDIX A

OVEN/INCINERATOR ANALYSIS MODEL SOFTWARE LISTING

```
1    1:D     1 (*$LREMOUT:*)
1    1:D     1 (*$S+*)
1    1:D     1 PROGRAM OVEN;
1    1:D     3 (* VERSION 2.2  *)
1    1:D     3 (*  30 MAY 1980 *)
1    1:D     3 (*  5:00 P.M.   *)
1    1:D     3
1    1:D     3 CONST VERS     = 2.0;
1    1:D     3       DFLTLEN = 30;
1    1:D     3       DESCLEN = 36;
1    1:D     3       UNITLEN = 24;
1    1:D     3       NUMITM  = 105;
1    1:D     3       RAL     = 60;
1    1:D     3       SAL     = 26;
1    1:D     3       LLT     = 29;
1    1:D     3       TRACER  = TRUE;
1    1:D     3       DEBUG   = FALSE;
1    1:D     3 TYPE FT=(NG,OIL,PROPANE);  (* FUEL TYPES *)
1    1:D     3      ST=0..9;   (* SOLVENT RANGE *)
1    1:D     3      ABT=1..2;  (* AFTERBURNER MODE *)
1    1:D     3                 (* [1]=AB,[2]=PREHEAT *)
1    1:D     3      ABARRAY = ARRAY[ABT] OF REAL;
1    1:D     3      SETOFCHAR = SET OF CHAR;
1    1:D     3 CRTCOMMAND= (ERASEOS,ERASEOL,UP,DOWN,RIGHT,LEFT,LEADIN);
1    1:D     3 VAR CH        : CHAR;
1    1:D     4     CRTINFO  : PACKED ARRAY[CRTCOMMAND] OF CHAR;
1    1:D     8     PREFIXED : ARRAY[CRTCOMMAND] OF BOOLEAN;
1    1:D    15     FILEIN   : STRING[30];
1    1:D    31     DEVICE   : STRING[10];
1    1:D    37
1    1:D    37           (***************************)
1    1:D    37           (*   GENERAL DEFINITIONS  *)
1    1:D    37           (***************************)
1    1:D    37 OPTIMIZE: BOOLEAN; (* CONTROLS OPTIMIZATION *)
1    1:D    38 FIRSTRD : BOOLEAN; (* FIRST READ OF OVEN-DEF *)
1    1:D    39 ENDRUN  : BOOLEAN;
1    1:D    40 PLNAME  : STRING[30]; (* PLANT NAME *)
1    1:D    56 PROCESS : STRING[30]; (* PROCESSING TYPE *)
1    1:D    72 DESCRP  : STRING[30]; (* DESCRIPTION *)
1    1:D    88 RUNNUM  : REAL;        (* RUN NUMBER *)
1    1:D    90 SYSDATE : STRING[12]; (* DATE OF DATA CREATION *)
1    1:D    97
1    1:D    97           (***************************)
1    1:D    97           (*    OVEN DEFINITIONS    *)
1    1:D    97           (***************************)
1    1:D    97 OVENTYPE: STRING[8];  (* OVEN TYPE *)
1    1:D   102 OVENEXIST : BOOLEAN;  (* EXISTING OVEN *)
1    1:D   103 OVENAIR : STRING[8];  (* AIR SOURCE *)
1    1:D   108 OVENFUEL: STRING[8];  (* FUEL TYPE *)
1    1:D   113 OFUEL   : FT;        (* FUEL USED *)
1    1:D   114 ACO     : REAL;      (* ANNUAL COST *)
1    1:D   116 AO      : REAL;      (* OVEN SURFACE AREA *)
1    1:D   118 CAE     : REAL;      (* EXCESS COMB AIR/100 *)
```

```
 54   1    1:D   120  CPC      : REAL;     (* SPECIFIC HEAT OF CONV *)
 55   1    1:D   122  CPLEL    : REAL;     (* CONTROL PLEL *)
 56   1    1:D   124  CPP      : REAL;     (* SPECIFIC HEAT OF PROD *)
 57   1    1:D   126  CRP      : REAL;     (* COATING RATE *)
 58   1    1:D   128  HP       : REAL;     (* ENTHALPY *)
 59   1    1:D   130  H        : ARRAY[0..5] OF REAL;(* ENTHALPIES *)
 60   1    1:D   142                       (* H0,H1,H2,H3,H4,H5 *)
 61   1    1:D   142  MC       : REAL;     (* CONV MASS FLOW RATE *)
 62   1    1:D   144  MFO      : REAL;     (* MASS FUEL FLOW  *)
 63   1    1:D   146  MM       : REAL;     (* MINIMUM AIR FLOW *)
 64   1    1:D   148  MP       : REAL;     (* PROD MASS FLOW RATE *)
 65   1    1:D   150  MR       : REAL;     (* % GASES RECYCLED *)
 66   1    1:D   152  MT       : REAL;     (* SYSTEM EXHAUST GAS RATE *)
 67   1    1:D   154                       (* MTO AND MTZ *)
 68   1    1:D   154  MV       : ARRAY[ST] OF REAL;(* SOLVENT RATE(0=H2O)*)
 69   1    1:D   174  MVSUM    : REAL;     (* SUM OF MV[I] *)
 70   1    1:D   176  MO       : REAL;     (* MF RATE OF COMB *)
 71   1    1:D   178  MOV      : REAL;     (* OVEN EXHAUST GAS RATE *)
 72   1    1:D   180  PLEL     : REAL;     (* % LEL / 100 *)
 73   1    1:D   182  QLO      : REAL;     (* HEAT LOSS *)
 74   1    1:D   184  TO       : REAL;     (* INLET AIR TEMP *)
 75   1    1:D   186  T1       : REAL;     (* EXHAUST GAS TEMP *)
 76   1    1:D   188  TP       : REAL;     (* PREHEAT AIR TEMP *)
 77   1    1:D   190  UO       : REAL;     (* HEAT TRANSFER COEFF *)
 78   1    1:D   192  DE       : REAL;     (* VOC EMISSION DESTRUCTION EFF *)
 79   1    1:D   194
 80   1    1:D   194           (***************************)
 81   1    1:D   194           (*    MIXING STATION       *)
 82   1    1:D   194           (***************************)
 83   1    1:D   194  HA       : REAL;     (* ENTHALPY AT TA              *)
 84   1    1:D   196  H1R      : REAL;     (* ENTHALPY AT MIXER           *)
 85   1    1:D   198  MSEXIST  : BOOLEAN;  (* MIXING STATION EXISTS       *)
 86   1    1:D   199  MSG      : REAL;     (* MASS FLOW RATE FROM AUX     *)
 87   1    1:D   201  PA       : REAL;     (* % TOTAL MASS FLOW FROM AUX *)
 88   1    1:D   203  PAN      : REAL;     (* COMPLIMENT OF PA            *)
 89   1    1:D   205  PLELA    : REAL;     (* PLEL OF MIXER               *)
 90   1    1:D   207  TA       : REAL;     (* EXHAUST TEMP FROM AUX       *)
 91   1    1:D   209  T1R      : REAL;     (* TEMP AT MIXER               *)
 92   1    1:D   211
 93   1    1:D   211           (***************************)
 94   1    1:D   211           (*     AFTERBURNER         *)
 95   1    1:D   211           (***************************)
 96   1    1:D   211  ABTYPE   : STRING[9];  (* AFTERBURNER TYPE *)
 97   1    1:D   216  ABEXIST  : BOOLEAN;    (* EXISTING AFTERBURNER *)
 98   1    1:D   217  ABFUEL   : STRING[8];  (* FUEL TYPE *)
 99   1    1:D   222  ABAIR    : STRING[8];  (* AIR SOURCE *)
100   1    1:D   227  AFUEL    : FT;         (* FUEL USED *)
101   1    1:D   228  ACI      : ABARRAY;    (* ANNUAL COST *)
102   1    1:D   232                        (* 1=ACIC OR ACIT, 2=PREHEAT *)
103   1    1:D   232  AI       : REAL;       (* AB SURFACE AREA          *)
104   1    1:D   234  HCI      : REAL;       (* ENTHALPY                 *)
105   1    1:D   236  HR       : REAL;       (* ENTHALPY                 *)
106   1    1:D   238  H3R,H60  : REAL;       (* ENTHALPY                 *)
```

```
107    1    1:D    242  MA       : REAL;         (* MF RATE OF COMB            *)
108    1    1:D    244  MFA      : ABARRAY;      (*MASS FUEL FLOW IN AB*)
109    1    1:D    248                        (* [1]=MFIT OR MFC,[2]=PREHEAT*)
110    1    1:D    248  MFB      : ABARRAY;      (* BOGUS FUEL FLOW *)
111    1    1:D    252  PLELR    : REAL;         (* PLEL OF AFTERBURNER        *)
112    1    1:D    254  QLI      : REAL;         (* HEAT LOSS IN AB            *)
113    1    1:D    256  TCI      : REAL;         (* TEMP AT HCI                *)
114    1    1:D    258  TCM      : REAL;         (* MAX T3 TEMP                *)
115    1    1:D    260  TR       : REAL;         (* CATALYTIC REACT TEMP       *)
116    1    1:D    262  T2       : ABARRAY;(* AB INLET TEMP,[1]=AB*)
117    1    1:D    266                           (* [2]=WITH PRIMARY PREHEAT*)
118    1    1:D    266  T2MAX    : REAL;         (* MAX INLET TEMP             *)
119    1    1:D    268  T2S      : REAL;         (* DESIRED AB INLET TEMP      *)
120    1    1:D    270  T3       : ABARRAY;      (* AB EXHAUST TEMP *)
121    1    1:D    274  T3S      : REAL;         (* AB EXHAUST TEMP            *)
122    1    1:D    276  UI       : REAL;         (* AB HEAT TRANSFER COEFF     *)
123    1    1:D    278
124    1    1:D    278             (***************************)
125    1    1:D    278             (*  PRIMARY HEAT RECOVERY *)
126    1    1:D    278             (***************************)
127    1    1:D    278  PEXIST   : BOOLEAN;      (* EXISTING PRIMARY H R  *)
128    1    1:D    279  PHR      : REAL;         (* PERCENT HEAT RECOVERY *)
129    1    1:D    281  PX       : REAL;         (* % EXHAUST GAS USED     *)
130    1    1:D    283  QPR      : REAL;         (* HEAT RECOVERED IN P H R *)
131    1    1:D    285  Q4       : REAL;         (* MAX HEAT AVAILABLE FOR SHR*)
132    1    1:D    287  T4       : ABARRAY;      (* EXHAUST TEMP  *)
133    1    1:D    291
134    1    1:D    291             (*****************************)
135    1    1:D    291             (* SECONDARY HEAT RECOVERY *)
136    1    1:D    291             (*****************************)
137    1    1:D    291  SEXIST   : BOOLEAN;      (* EXISTING SECONDARY H R *)
138    1    1:D    292  SHRTYPE  : STRING[8];    (* TYPE OF SECONDARY H R *)
139    1    1:D    297  ACR      : ABARRAY;      (*REVISED ANNUAL COST *)
140    1    1:D    301  ACSIP    : ABARRAY;      (*ANNUAL OVEN FUEL SAVED*)
141    1    1:D    305  AES      : ABARRAY;      (*ANNUAL ENERGY SAVED *)
142    1    1:D    309  HSTM,H200: REAL;         (* ENTHALPY *)
143    1    1:D    313  HOPRIME  : REAL;         (* ENTHALPY *)
144    1    1:D    315  MAH      : REAL;         (* % RECYCLED AIR TO OVEN *)
145    1    1:D    317  MAHO     : ABARRAY;      (* OPTIMUM RECYCLED AIR*)
146    1    1:D    321  MFR      : ABARRAY;      (* REVISED MASS FLOW *)
147    1    1:D    325  MSTM     : ABARRAY;      (* MASS RATE OF STEAM *)
148    1    1:D    329  QSR      : ABARRAY;      (* HEAT RECOVERED *)
149    1    1:D    333  RESC     : ARRAY[ABT] OF BOOLEAN;(* PRINT MAH     *)
150    1    1:D    335  TOPRIME  : ABARRAY;      (* REVISED OVEN TO *)
151    1    1:D    339  T5       : REAL;         (* EXHAUST GAS TEMP TO ATM *)
152    1    1:D    341  WHBS     : ARRAY[FT,ABT] OF REAL;(* SAVINGS EACH FUEL *)
153    1    1:D    353
154    1    1:D    353             (***************************)
155    1    1:D    353             (*    ECONOMIC FACTORS     *)
156    1    1:D    353             (***************************)
157    1    1:D    353  AH : REAL;       (* ANNUAL OPERATING HRS *)
158    1    1:D    355  FC : ARRAY[FT] OF REAL;(* FUEL COSTS *)
159    1    1:D    361  IR : REAL;       (* INTEREST RATE /100 *)
```

```
 160   1    1:D   363  NY : REAL;        (* LIFE OF PROJECT *)
 161   1    1:D   365  EPC : REAL;       (* EXISTING PLANT ANNUAL FUEL COSTS *)
 162   1    1:D   367
 163   1    1:D   367            (**************************)
 164   1    1:D   367            (*    CONSTANT FACTORS    *)
 165   1    1:D   367            (**************************)
 166   1    1:D   367  CAF    : ARRAY[FT] OF REAL;(* THEOR COMB AIR FOR FUEL *)
 167   1    1:D   373  HHVF   : ARRAY[FT] OF REAL;(* HIGH HEAT VALUE OF FUEL *)
 168   1    1:D   379  LHVF   : ARRAY[FT] OF REAL;(* LOW  HEAT VALUE OF FUEL *)
 169   1    1:D   385  FDCF   : ARRAY[FT] OF REAL;(* DENSITY CONVER FACTORS *)
 170   1    1:D   391  DCU    : ARRAY[FT] OF STRING[6];(* DENS CONVRSN UNITS *)
 171   1    1:D   403
 172   1    1:D   403            (**************************)
 173   1    1:D   403            (*      SOLVENT DATA      *)
 174   1    1:D   403            (**************************)
 175   1    1:D   403  CAV    : ARRAY[ST] OF REAL;(* THEOR COMB AIR OF SOLV *)
 176   1    1:D   423  DHVV   : ARRAY[ST] OF REAL;(* HEAT OF VAPOR OF SOLV *)
 177   1    1:D   443  LELV   : ARRAY[ST] OF REAL;(* LOWER EXPL LIM OF SOLV *)
 178   1    1:D   463  LELMIN: INTEGER;         (* INDEX OF MIN OF LELV[I] *)
 179   1    1:D   464  LHVV   : ARRAY[ST] OF REAL;(* LOW HEAT VALUE OF SOLV *)
 180   1    1:D   484  NS     : INTEGER;         (* NUMBER OF SOLVS *)
 181   1    1:D   485  SLVNM  : ARRAY[ST] OF STRING[30]; (* SOLV NAMES *)
 182   1    1:D   645  SLVWT  : ARRAY[ST] OF REAL;(* SOLV % COMPOSITION *)
 183   1    1:D   665  SVSV   : ARRAY[ST] OF REAL;(* SPECIFIC VOLUME OF SOLV *)
 184   1    1:D   685  LTAB   : ARRAY[1..2,1..LLT] OF REAL;(*1=TEMP,2=H'PY*)
 185   1    1:D   801
 186   1    1:D   801            (**************************)
 187   1    1:D   801            (*    REPORT ARRAYS       *)
 188   1    1:D   801            (**************************)
 189   1    1:D   801
 190   1    1:D   801  RPTBTU: ARRAY[1..2,1..6] OF REAL;(* BTU FIGURES FOR RE-
PORT *)
 191   1    1:D   825  RPTDOL: ARRAY[1..2,1..6] OF REAL;(* DOLLAR FIGURES FOR
REPORT *)
 192   1    1:D   849
 193   1    1:D   849
 194   1    1:D   849            (**************************)
 195   1    1:D   849            (*     OVEN-DEF DATA      *)
 196   1    1:D   849            (**************************)
 197   1    1:D   849
 198   1    1:D   849  AD    : ARRAY[0..RAL] OF REAL;(* REAL INPUT *)
 199   1    1:D   971  SG    : ARRAY[0..SAL] OF STRING[DFLTLEN];(*STR INPUT*)
 200   1    1:D  1403  MRAL,MSAL : INTEGER;
 201   1    1:D  1405  RUNDATE : STRING[12];
 202   1    1:D  1412  MID,MST,MED,MF1,MF2,MRPT,MACT,MIND:
 203   1    1:D  1412     ARRAY[0..NUMITM] OF INTEGER;
 204   1    1:D  2260  ITEM, ITM, MS, ME, N : INTEGER;
 205   1    1:D  2265  MDES: ARRAY[0..NUMITM] OF STRING[DESCLEN];
 206   1    1:D  4279  MUNT: ARRAY[0..NUMITM] OF STRING[UNITLEN];
 207   1    1:D  5657  SUCESSFUL,ENDER : BOOLEAN;
 208   1    1:D  5659  MAXI : INTEGER;
 209   1    1:D  5660  NUMBER : SET OF CHAR;
 210   1    1:D  5676  DOTS : STRING[40];
```

```
211    1     1:D  5697  NSTR  : STRING[DFLTLEN];
212    1     1:D  5713  NSAVE : ARRAY[1..10] OF INTEGER;
213    1     1:D  5723
214    1     1:D  5723 (**************************)
215    1     2:D     1 PROCEDURE PROMPTAT(Y: INTEGER; S: STRING);FORWARD;
216    1     3:D     1 PROCEDURE CRT(C: CRTCOMMAND);FORWARD;
217    1     4:D     3 FUNCTION  YES:BOOLEAN; FORWARD;
218    1     5:D     3 FUNCTION  RVAL(S:STRING):REAL; FORWARD;
219    1     5:D    45
220    1     5:D    45        (**************************)
220    1     5:D    45 (*$P,IPROGS:MODIFY.TEXT*)
221    1     5:D    45 (* MODIFY.TEXT *)
222    1     5:D    45 (* UPDATED 27 MAR 1980 *)
223    1     5:D    45 (*  5:30 P.M. *)
224    7     1:D     1 SEGMENT PROCEDURE MODIFY;
225    7     1:D     1 CONST PAUSETM = 1000;
226    7     1:D     1 TYPE MENUITEM = RECORD
227    7     1:D     1        MITEM     : 0..NUMITM;
228    7     1:D     1        MIDENT    : -4..32;
229    7     1:D     1        MDESCPT   : STRING[DESCLEN];
230    7     1:D     1        MUNITSM   : STRING[UNITLEN];
231    7     1:D     1        MSTART    : 0..NUMITM;
232    7     1:D     1        MEND      : 0..NUMITM;
233    7     1:D     1        MFORM1    : -80..20;
234    7     1:D     1        MFORM2    : 0..20;
235    7     1:D     1        MREPEAT   : 0..1023;
236    7     1:D     1        MACTRPT   : 0..NUMITM;
237    7     1:D     1        MINDEX    : 0..8191;
238    7     1:D     1        MDEFAULT  : STRING[DFLTLEN];
239    7     1:D     1       END;
240    7     1:D     1
241    7     1:D     1 VAR I,NS,L  : INTEGER;
242    7     1:D     4     DATAFILE: FILE OF MENUITEM;
243    7     1:D   361     DFILE   : TEXT;
244    7     1:D   662
245    7     2:D     1 PROCEDURE GETCRTINFO;
246    7     2:D     1 (*******************************************************)
247    7     2:D     1 (* READ SYSTEM.MISCINFO AND GET CRT CONTROL CHAR INFO*)
248    7     2:D     1 (*******************************************************)
249    7     2:D     1 VAR BUFFER: PACKED ARRAY[0..511] OF CHAR;
250    7     2:D   257     I,BYTE: INTEGER;
251    7     2:D   259     F: FILE;
252    7     2:0     0 BEGIN
253    7     2:1     0   RESET(F,'*SYSTEM.MISCINFO');
254    7     2:1    42   I:=BLOCKREAD(F,BUFFER,1);
255    7     2:1    64   CLOSE(F);
256    7     2:1    73   BYTE:=ORD(BUFFER[72]); (* PREFIX INFORMATION BYTE *)
257    7     2:1    85   CRTINFO[LEADIN]:=BUFFER[62];
258    7     2:1   101   PREFIXED[LEADIN]:=FALSE;
259    7     2:1   111   CRTINFO[ERASEOS]:=BUFFER[64];
260    7     2:1   127   PREFIXED[ERASEOS]:=ODD(BYTE DIV 8);
261    7     2:1   141   CRTINFO[ERASEOL]:=BUFFER[65];
262    7     2:1   157   PREFIXED[ERASEOL]:=ODD(BYTE DIV 4);
```

```
7   2:1   171   CRTINFO[RIGHT]:=BUFFER[66];
7   2:1   187   PREFIXED[RIGHT]:=ODD(BYTE DIV 2);
7   2:1   201   CRTINFO[UP]:=BUFFER[67];
7   2:1   217   PREFIXED[UP]:=ODD(BYTE);
7   2:1   229   CRTINFO[LEFT]:=BUFFER[68];
7   2:1   245   PREFIXED[LEFT]:=ODD(BYTE DIV 32);
7   2:1   259   CRTINFO[DOWN]:=CHR(10);
7   2:1   267   PREFIXED[DOWN]:=FALSE;
7   2:0   277 END;
7   2:0   296
7   2:0   296
7   2:0   296 (***************************)
7   2:0   296
7   3:D     1 PROCEDURE PAUSER(M:INTEGER);
7   3:D     2 VAR I,J: INTEGER;
7   3:0     0 BEGIN
7   3:1     0   FOR I := 1 TO M*PAUSETM DO
7   3:2    15     J := I;
7   3:0    25 END; (* PAUSER *)
7   3:0    40
7   3:0    40
7   3:0    40 (* VALIDATE STRING *)
7   4:D     3 FUNCTION VALIDS(I:INTEGER; NSTR:STRING):BOOLEAN;
7   4:D    46 VAR VLD     : BOOLEAN;
7   4:D    47     L,LL,M,N: INTEGER;
7   4:D    51     CST     : STRING;
7   4:D    92
7   4:0     0 BEGIN
7   4:1     0   VLD := FALSE;
7   4:1     8   L := LENGTH(NSTR);
7   4:1    14   LL := LENGTH(MUNT[I]);
7   4:1    27   IF (L = 0) OR (LL = 0)
7   4:1    35     THEN VLD := TRUE
7   4:1    38     ELSE IF L <= ABS(MF1[I])
7   4:2    56       THEN BEGIN
7   4:4    59         M := 1;
7   4:4    62         REPEAT
7   4:5    62           CST := COPY(MUNT[I],M,LL-M+1);
7   4:5    91           N := SCAN(LL-M+1,='/',CST);
7   4:5   108           IF N < LL-M+1 THEN N := N -1;
7   4:5   126           IF NSTR = COPY(CST,1,N)
7   4:5   140             THEN VLD := TRUE
7   4:5   144             ELSE M := M + N + 1;
7   4:4   158         UNTIL VLD OR (M > LL);
7   4:3   168       END;
7   4:1   168   IF NOT VLD
7   4:1   168     THEN WRITELN('INVALID ENTRY. PLEASE REENTER.');
7   4:1   223   VALIDS := VLD;
7   4:0   227 END; (* VALIDS *)
7   4:0   242
7   4:0   242 (* VALIDATE REAL OR INTEGER *)
7   5:D     3 FUNCTION VALIDR(I:INTEGER; NSTR:STRING):BOOLEAN;
7   5:D    46 VAR VLD     : BOOLEAN;
```

```
316   7   5:D    47      K,L,M,N : INTEGER;
317   7   5:D    51      CST     : STRING;
318   7   5:D    92
319   7   5:0     0 BEGIN
320   7   5:1     0   VLD := FALSE;
321   7   5:1     8   CST := NSTR;
322   7   5:1    14   L := LENGTH(CST);
323   7   5:1    20   M := SCAN(L,<>' ',CST[1]);
324   7   5:1    33   IF M > 0 THEN
325   7   5:2    39     CST := COPY(CST,M+1,L-M);
326   7   5:1    61   M := POS('+',CST);
327   7   5:1    74   IF M > 0 THEN
328   7   5:2    80     CST := COPY(CST,M+1,LENGTH(CST)-M);
329   7   5:1   104   M := POS('-',CST);
330   7   5:1   117   IF M > 0 THEN
331   7   5:2   123     CST := COPY(CST,M+1,LENGTH(CST)-M);
332   7   5:1   147   N := POS('.',CST) - 1;
333   7   5:1   162   IF N < 0 THEN N := LENGTH(CST);
334   7   5:1   174   IF   ((MF2[I]= 0) AND (N<=MF1[I]))
335   7   5:1   200     OR ((MF2[I]<>0) AND (N<=(MF1[I]-MF2[I]-1)))
336   7   5:1   239       THEN VLD := TRUE;
337   7   5:1   245   IF NOT VLD
338   7   5:1   245     THEN WRITELN('INVALID ENTRY. PLEASE REENTER.');
339   7   5:1   300   VALIDR := VLD;
340   7   5:0   304 END;  (* VALIDR *)
341   7   5:0   316
342   7   6:D     3 FUNCTION MAX(M,N:INTEGER):INTEGER;
343   7   6:0     0 BEGIN
344   7   6:1     0   IF M > N
345   7   6:1     1     THEN MAX := M
346   7   6:1     5     ELSE MAX := N;
347   7   6:0    13 END;  (* MAX *)
348   7   6:0    26
349   7   6:0    26
350   7   7:D     1 PROCEDURE INPDATA;
351   7   7:D     1 VAR I       : INTEGER;
352   7   7:D     2
353   7   8:D     1 PROCEDURE READATA;
354   7   8:D     1 VAR I : INTEGER;
355   7   8:0     0 BEGIN
356   7   8:1     0   WRITELN;
357   7   8:1     8   WRITELN('INPUT DATA BEING READ.');
358   7   8:1    50   READLN(DFILE,MSAL,MRAL);
359   7   8:1    83   FOR I := 1 TO MSAL DO
360   7   8:2    96     BEGIN
361   7   8:3    96       READLN(DFILE,SG[I]);
362   7   8:2   124     END;
363   7   8:1   131   FOR I := 1 TO MRAL DO
364   7   8:2   144     BEGIN
365   7   8:3   144       READLN(DFILE,AD[I]);
366   7   8:2   171     END;
367   7   8:1   178   CLOSE(DFILE);
368   7   8:0   188 END; (* READATA *)
```

```
 7    8:0   204
 7    9:D     1 PROCEDURE DINIT(I:INTEGER);
 7    9:D     2 VAR M : INTEGER;
 7    9:0     0 BEGIN
 7    9:1     0     IF MF1[I] < 0
 7    9:1    10     THEN BEGIN
 7    9:3    14       M  := MIND[I];
 7    9:3    26       IF M <= SAL
 7    9:3    27       THEN BEGIN
 7    9:5    31         MSAL := MAX(MSAL,M);
 7    9:5    42         SG[M] := DATAFILE@.MDEFAULT
 7    9:4    54       END
 7    9:3    58       ELSE BEGIN
 7    9:5    60         WRITELN('RANGE ERROR ON ',I,' = ',M);
 7    9:4   130       END;
 7    9:2   130     END;
 7    9:1   130     IF MF1[I] > 0
 7    9:1   140     THEN BEGIN
 7    9:3   144       M  := MIND[I];
 7    9:3   156       IF M <= RAL
 7    9:3   157       THEN BEGIN
 7    9:5   161         MRAL := MAX(MRAL,M);
 7    9:5   172         AD[M] := RVAL(DATAFILE@.MDEFAULT);
 7    9:4   193       END
 7    9:3   193       ELSE BEGIN
 7    9:5   195         WRITELN('RANGE ERROR ON ',I,' = ',M);
 7    9:4   265       END;
 7    9:2   265     END;
 7    9:0   265 END; (* DINIT *)
 7    9:0   278
 7   10:D     1 PROCEDURE FILEDEFS;
 7   10:D     1 VAR SUCESSFUL: BOOLEAN;
 7   10:D     2     DEFILE    : STRING[30];
 7   10:D    18     I         : INTEGER;
 7   10:0     0 BEGIN
 7   10:1     0   FOR I := 0 TO RAL DO
 7   10:2    13     AD[I] := 0;
 7   10:1    35   FOR I := 0 TO SAL DO
 7   10:2    48     SG[I] := ' ';
 7   10:1    69   FOR I := 0 TO NUMITM DO BEGIN
 7   10:3    82     MID[I]  := 0;
 7   10:3    94     MDES[I] := ' ';
 7   10:3   107     MUNT[I] := ' ';
 7   10:3   120     MST[I]  := 0;
 7   10:3   132     MED[I]  := 0;
 7   10:3   144     MF1[I]  := 0;
 7   10:3   156     MF2[I]  := 0;
 7   10:3   168     MRPT[I] := 0;
 7   10:3   180     MACT[I] := 0;
 7   10:3   192     MIND[I] := 0;
 7   10:2   204   END; (* FOR I *)
 7   10:2   212     (*$I-*)
 7   10:1   212   GOTOXY(0,1); CRT(ERASEOS);
```

```
422   7   10:1   221    DEFILE := 'OVEN-DEF';
423   7   10:1   236    REPEAT
424   7   10:2   236      IF LENGTH(DEFILE) > 0
425   7   10:2   240        THEN BEGIN
426   7   10:4   244          RESET(DATAFILE,DEFILE);
427   7   10:4   254          SUCESSFUL := (IORESULT=0);
428   7   10:4   260          IF NOT SUCESSFUL
429   7   10:4   260          THEN BEGIN
430   7   10:6   264            WRITELN('FILE NOT FOUND.  REENTER.');
431   7   10:6   305            WRITE('INPUT DEFINITION File Name: ');
432   7   10:6   343            READLN(DEFILE);
433   7   10:5   358          END;
434   7   10:3   358        END
435   7   10:2   358        ELSE EXIT(PROGRAM);
436   7   10:1   364    UNTIL SUCESSFUL;
437   7   10:0   367  END; (* FILEDEFS *)
438   7   10:0   390
439   7    7:0     0  BEGIN (* INPDATA *)
440   7    7:1     0    FILEDEFS;
441   7    7:1     2    WRITELN;
442   7    7:1     8    WRITELN('ENTER FILE NAME FOR INPUT OR <RETURN>');
443   7    7:1    61    WRITE('FOR KEYBOARD ENTRY ');
444   7    7:1    90    REPEAT
445   7    7:2    90      READLN(FILEIN);
446   7    7:2   105      L := LENGTH(FILEIN);
447   7    7:2   112      IF L = 0
448   7    7:2   115        THEN BEGIN (* KEYBOARD INPUT *)
449   7    7:4   119          SUCESSFUL := TRUE;
450   7    7:3   123        END
451   7    7:2   123        ELSE BEGIN (* FILE INPUT *)
452   7    7:4   125          IF COPY(FILEIN,LENGTH(FILEIN)-4,5)
453   7    7:4   141             <> '.TEXT'
454   7    7:4   141             THEN FILEIN := CONCAT(FILEIN,'.TEXT');
455   7    7:4   184          RESET(DFILE,FILEIN);
456   7    7:4   195          SUCESSFUL := (IORESULT=0);
457   7    7:4   202          IF NOT SUCESSFUL
458   7    7:4   202           THEN WRITELN('FILE NOT FOUND.  REENTER');
459   7    7:3   248        END;
460   7    7:1   248    UNTIL SUCESSFUL;
461   7    7:1   253    WRITELN;
462   7    7:1   259    WRITELN('DEFINITION FILE BEING READ.');
463   7    7:1   302    SEEK(DATAFILE,0);
464   7    7:1   309    GET(DATAFILE);
465   7    7:1   315    MAXI := -1;
466   7    7:1   320    IF (IORESULT=0) THEN
467   7    7:2   326      FOR I := 0 TO NUMITM DO BEGIN
468   7    7:4   337        WITH DATAFILE@ DO BEGIN
469   7    7:6   342          IF (MITEM <= NUMITM) AND
470   7    7:6   346           ( ((MAXI<0) AND (MITEM=0)) OR (MITEM>0))
471   7    7:6   361            THEN BEGIN
472   7    7:8   364              MID[MITEM]  := MIDENT;
473   7    7:8   377              MDES[MITEM] := MDESCPT;
474   7    7:8   392              MUNT[MITEM] := MUNITSM;
```

```
475   7    7:8   407              MST[MITEM]  := MSTART;
476   7    7:8   421              MED[MITEM]  := MEND;
477   7    7:8   435              MF1[MITEM]  := MFORM1;
478   7    7:8   449              MF2[MITEM]  := MFORM2;
479   7    7:8   463              MRPT[MITEM] := MREPEAT;
480   7    7:8   477              MACT[MITEM] := MACTRPT;
481   7    7:8   491              MIND[MITEM] := MINDEX;
482   7    7:8   505              MAXI  := MAX(MAXI,MITEM);
483   7    7:8   517              IF L=0 THEN DINIT(I);
484   7    7:7   527            END;
485   7    7:5   527        END; (* WITH DATAFILE DO *)
486   7    7:4   527        GET(DATAFILE);
487   7    7:3   533      END; (* FOR I *)
488   7    7:1   540    CLOSE(DATAFILE);
489   7    7:1   547
490   7    7:1   547    IF L>0 THEN READATA;
491   7    7:0   556 END; (* INPDATA *)
492   7    7:0   578
493   7    7:0   578
494   7   11:D     1 PROCEDURE MENU(N,M1,M2:INTEGER;VAR IT:INTEGER);
495   7   11:D     5 VAR L,I,J : INTEGER;
496   7   11:0     0 BEGIN
497   7   11:1     0   IF N > NS THEN NSAVE[N] := IT;
498   7   11:1    21   NS := N;
499   7   11:1    25   GOTOXY(0,0); CRT(ERASEOS);
500   7   11:1    34
501   7   11:1    34   (* PRINT HEADINGS *)
502   7   11:1    34   FOR I := 1 TO N DO
503   7   11:2    45   BEGIN
504   7   11:3    45     L := TRUNC(20-LENGTH(MDES[NSAVE[I]])/2.0);
505   7   11:3    82     WRITELN(' ':L,MDES[NSAVE[I]]);WRITELN;
506   7   11:2   129   END;
507   7   11:2   136
508   7   11:2   136   (* PRINT MENU *)
509   7   11:1   136   FOR I := M1 TO M2 DO
510   7   11:2   147   BEGIN
511   7   11:3   147     L := 40 - LENGTH(MDES[I]) -1;
512   7   11:3   164     WRITELN(MDES[I],COPY(DOTS,1,L),I-M1);
513   7   11:3   215     WRITELN;
514   7   11:2   221   END;
515   7   11:2   228
516   7   11:2   228   (* PROMPT FOR RESPONSE *)
517   7   11:1   228   REPEAT
518 228     WRITE('->'); READLN(J);
519   7   11:1   254   UNTIL (J>=0) AND (J<=(M2-M1));
520   7   11:1   265   IT := M1 + J;
521   7   11:0   270 END; (* MENU *)
522   7   11:0   288
523   7   12:D     1 PROCEDURE VALUE(IT:INTEGER);
524   7   12:D     2 VAR I,F1,F2,RC,K : INTEGER;
525   7   12:D     7     F3  : REAL;
526   7   12:D     9     GOOD : BOOLEAN;
527   7   12:0     0 BEGIN
```

```
528   7   12:1     0  IF MACT[IT] > 0
529   7   12:1    10    THEN RC := TRUNC(AD[MIND[MACT[IT]]])
530   7   12:1    45    ELSE RC := MRPT[IT];
531   7   12:1    61  FOR K := 0 TO RC-1 DO
532   7   12:2    74  BEGIN
533   7   12:3    74    FOR I := MST[IT] TO MED[IT] DO
534   7   12:4   103    REPEAT
535   7   12:5   103      WRITELN;
536   7   12:5   109      IF RC>1 THEN WRITE('#',K,': ');
537   7   12:5   142      WRITELN(MDES[I]);
538   7   12:5   164      IF LENGTH(MUNT[I]) > 0
539   7   12:5   175        THEN WRITELN('(',MUNT[I],')');
540   7   12:5   217      IF MF1[I] < 0
541   7   12:5   227      THEN BEGIN  (* STRING *)
542   7   12:7   231        WRITELN(SG[MIND[I]+K]);
543   7   12:7   264         READLN(NSTR);
544   7   12:7   280        IF LENGTH(NSTR) > 0
545   7   12:7   285        THEN BEGIN
546   7   12:9   289          GOOD := VALIDS(I,NSTR);
547   7   12:9   299          IF GOOD THEN
548   7   12:0   302            SG[MIND[I]+K] := NSTR;
549   7   12:8   327        END
550   7   12:7   327        ELSE GOOD := TRUE;
551   7   12:7   332        MSAL := MAX(MSAL,MIND[I]+K);
552   7   12:6   354      END
553   7   12:5   354      ELSE
554   7   12:6   356        IF MF1[I]>0
555   7   12:6   366        THEN BEGIN  (* REAL *)
556   7   12:8   370          F1 := MF1[I];
557   7   12:8   382          F2 := MF2[I];
558   7   12:8   394          F3 := AD[MIND[I]+K];
559   7   12:8   420          IF F2 > 0
560   7   12:8   421            THEN WRITELN(F3:F1:F2)
561   7   12:8   443            ELSE
562   7   12:9   445              IF F3 < MAXINT
563   7   12:9   449                THEN WRITELN(TRUNC(F3):F1)
564   7   12:9   476                ELSE WRITELN(F3:F1+2:1);
565   7   12:8   498          READLN(NSTR);
566   7   12:8   514          IF LENGTH(NSTR) > 0
567   7   12:8   519          THEN BEGIN
568   7   12:0   523            GOOD := VALIDR(I,NSTR);
569   7   12:0   533            IF GOOD THEN
570   7   12:1   536              AD[MIND[I]+K] := RVAL(NSTR);
571   7   12:9   566          END
572   7   12:8   566          ELSE GOOD := TRUE;
573   7   12:8   571          MRAL := MAX(MRAL,MIND[I]+K);
574   7   12:7   593        END;
575   7   12:4   593     UNTIL GOOD; (* FOR I *)
576   7   12:2   603   END; (* FOR K *)
577   7   12:0   610 END; (* VALUE *)
578   7   12:0   636
579   7   13:D     1 PROCEDURE UPDATE;
580   7   13:0     0 BEGIN
```

```
 7  13:1    0    WRITELN;
 7  13:1    6    WRITE('DO YOU WISH TO MODIFY ANY INPUT DATA? ');
 7  13:1   54    IF YES THEN BEGIN
 7  13:3   61      WRITELN;
 7  13:3   67      WRITELN;
 7  13:3   73      WRITELN('ENTER CHANGES TO VALUES OR <RETURN> TO ');
 7  13:3  128      WRITELN(' ACCEPT CURRENT VALUES ').
 7  13:3  167      PAUSER(3);
 7  13:3  170      ITEM := 0;
 7  13:3  174      ITM := 0;
 7  13:3  178      MS := MST[ITEM];
 7  13:3  193      ME := MED[ITEM];
 7  13:3  208      N := 1;
 7  13:3  212      NS := 0;
 7  13:3  216      REPEAT
 7  13:4  216        IF MID[ITEM] >= 0
 7  13:4  228        THEN BEGIN  (* MENU *)
 7  13:6  232          MENU(N,MS,ME,ITM);
 7  13:6  246          IF MID[MST[ITM]] >= 0
 7  13:6  267          THEN BEGIN
 7  13:8  271            ITEM := ITM;
 7  13:8  277            MS := MST[ITEM];
 7  13:8  292            ME := MED[ITEM];
 7  13:8  307            IF MID[ITEM] > 0
 7  13:8  319              THEN N := N + 1
 7  13:8  326              ELSE N := N - 1;
 7  13:7  341          END;
 7  13:5  341        END; (* MENU *)
 7  13:4  341        IF MID[MST[ITM]] < 0
 7  13:4  362          THEN VALUE(ITM);
 7  13:3  371    UNTIL (MS=0) AND (ME=0);
 7  13:2  384  END
 7  13:1  384  ELSE BEGIN
 7  13:3  386    WRITELN;
 7  13:3  392    ENDER := TRUE;
 7  13:2  396  END;
 7  13:0  396 END; (*UPDATE *)
 7  13:0  412
 7  14:D    1 PROCEDURE SAVEFILE;
 7  14:D    1 VAR FOUT : STRING[30];
 7  14:D   17     I :  INTEGER;
 7  14:0    0 BEGIN
 7  14:1    0   WRITELN;
 7  14:1    6   WRITELN('ENTER FILE NAME TO SAVE UPDATED VALUES ');
 7  14:1   61   READLN(FOUT);
 7  14:1   76   IF LENGTH(FOUT) > 0
 7  14:1   80     THEN BEGIN
 7  14:3   84       IF COPY(FOUT,LENGTH(FOUT)-4,5) <> '.TEXT'
 7  14:3  100         THEN FOUT := CONCAT(FOUT,'.TEXT');
 7  14:3  143       REWRITE(DFILE,FOUT);
 7  14:3  154       WRITELN(DFILE,MSAL,' ',MRAL);
 7  14:3  192       FOR I := 1 TO MSAL DO
 7  14:4  207         WRITELN(DFILE,SG[I]);
```

```
634    7   14:3   240         FOR I := 1 TO MRAL DO
635    7   14:4   255           WRITELN(DFILE,AD[I]);
636    7   14:3   291         CLOSE(DFILE,LOCK);
637    7   14:2   299       END;
638    7   14:0   299 END; (* SAVEFILE *)
639    7   14:0   318
640    7    1:0     0 BEGIN  (* MODIFY *)
641    7    1:1     0   ENDER := FALSE;
642    7    1:1    26   IF FIRSTRD
643    7    1:1    26   THEN BEGIN
644    7    1:3    30     FILLCHAR(DOTS,40,'.');
645    7    1:3    38     NUMBER := ['0'..'9'];
646    7    1:3    57     MSAL := 0; MRAL := 0;
647    7    1:3    65     GETCRTINFO;
648    7    1:2    67   END;
649    7    1:1    67   GOTOXY(0,0); CRT(ERASEOS);
650    7    1:1    76   IF FIRSTRD THEN INPDATA;
651    7    1:1    82   FIRSTRD := FALSE;
652    7    1:1    85   REPEAT
653    7    1:2    85     UPDATE;
654    7    1:2    87     IF NOT ENDER THEN SAVEFILE;
655    7    1:1    95   UNTIL ENDER;
656    7    1:1   100   WRITELN;
657    7    1:1   106   WRITELN('END OF INPUT UPDATE.');
658    7    1:0   142 END; (* MODIFY *)
659    7    1:0   170
660    7    1:0   170
661    7    1:0   170 (*$P,IPROGS:MODIFY.TEXT*)
661    7    1:0   170 (*$P,IPROGS:INDATA.TEXT*)
662    7    1:0   170 (* INDATA.TEXT *)
663    7    1:0   170 (* 30 MAY 1980 *)
664    7    1:0   170 (* 12:30 P.M. *)
665    7    1:0   170
666    8    1:D     1 SEGMENT PROCEDURE INDATA;
667    8    1:D     1 VAR   STR : STRING[30];
668    8    1:D    17       DATAFILE:  TEXT;
669    8    1:D   318       I : INTEGER;
670    8    1:D   319       NUMBER :  SET OF CHAR;
671    8    1:D   335
672    8    1:D   335
673    8    2:D     1 PROCEDURE OLDFILE;
674    8    2:D     1 VAR SUCESSFUL: BOOLEAN;
675    8    2:D     2     I : INTEGER;
676    8    2:0     0 BEGIN
677    8    2:0     0   (*$I-*)
678    8    2:1     0   GOTOXY(0,1); CRT(ERASEOS);
679    8    2:1     9   REPEAT
680    8    2:2     9     WRITE('ENTER INITIAL DATA File Name: ');
681    8    2:2    49     READLN(FILEIN);
682    8    2:2    64       IF LENGTH(FILEIN) > 0
683    8    2:2    68         THEN BEGIN
684    8    2:4    72           IF (LENGTH(FILEIN) < 6) OR
685    8    2:4    78              (COPY(FILEIN,LENGTH(FILEIN)-4,5)
8  2:4    94                    <> '.TEXT')
8  2:4   104                     THEN FILEIN := CONCAT(FILEIN,'.TEXT');
8  2:4   138                 RESET(DATAFILE,FILEIN);(* OPEN FILE *)
8  2:4   148                 SUCESSFUL := (IORESULT=0);
8  2:4   154                 IF NOT SUCESSFUL THEN
8  2:5   158                   WRITELN(FILEIN,' FILE NOT FOUND.  REENTER.');
8  2:3   209                     END
8  2:2   209              ELSE EXIT(PROGRAM);
8  2:1   215      UNTIL SUCESSFUL;
8  2:1   218
8  2:1   218      (* READ INPUT VALUES *)
8  2:1   218      WRITELN;
8  2:1   224      WRITELN('INITIAL VALUES BEING READ.');
8  2:1   266      READLN(DATAFILE,MSAL,MRAL);
8  2:1   290      FOR I := 1 TO MSAL DO
8  2:2   303        BEGIN
8  2:3   303           READLN(DATAFILE,SG[I]);
8  2:3   325           (* IF DEBUG THEN
8  2:3   325             WRITELN('SG[',I,'] = ',SG[I]);*)
8  2:2   325        END;
8  2:1   332      FOR I := 1 TO MRAL DO
8  2:2   345        BEGIN
8  2:3   345           READLN(DATAFILE,AD[I]);
8  2:3   366           (* IF DEBUG THEN
8  2:3   366             WRITELN('AD[',I,'] = ',AD[I]);*)
8  2:2   366        END;
8  2:1   373        CLOSE(DATAFILE);
8  2:0   380  END; (* OLDFILE *)
8  2:0   400
8  3:D     1  PROCEDURE INITDATA;
8  3:D     1  VAR J : INTEGER;
8  3:D     2
8  3:0     0  BEGIN
8  3:1     0    IF FIRSTRD THEN OLDFILE;
8  3:1     6
8  3:1     6    OVENEXIST := (SG[1] = 'Y');
8  3:1    20    ABEXIST   := (SG[2] = 'Y');
8  3:1    35    PEXIST    := (SG[3] = 'Y');
8  3:1    50    SEXIST    := (SG[4] = 'Y');
8  3:1    65    ABTYPE    := SG[5];
8  3:1    79    ABFUEL    := SG[6];
8  3:1    93    ABAIR     := SG[7];
8  3:1   107    SHRTYPE   := SG[8];
8  3:1   121    OVENTYPE  := SG[9];
8  3:1   134    OVENFUEL  := SG[10];
8  3:1   147    OVENAIR   := SG[11];
8  3:1   160    SYSDATE   := SG[12];
8  3:1   173    PLNAME    := SG[13];
8  3:1   186    PROCESS   := SG[14];
8  3:1   199    DESCRP    := SG[15];
8  3:1   212    MSEXIST   := (SG[16] = 'Y');
8  3:1   227
8  3:1   227    UI        := AD[1];
```

```
739   8   3:1   243   AI          := AD[2];
740   8   3:1   259   T2S         := AD[3];
741   8   3:1   275   T3S         := AD[4];
742   8   3:1   291   TR          := AD[5];
743   8   3:1   307   PX          := AD[6]/100.0;
744   8   3:1   331   T5          := AD[7];
745   8   3:1   347   MAH         := AD[9]/100.0;
746   8   3:1   371   IR          := AD[11];
747   8   3:1   387   NY          := AD[12];
748   8   3:1   403   AH          := AD[13];
749   8   3:1   419   UO          := AD[15];
750   8   3:1   435   AO          := AD[16];
751   8   3:1   450   MR          := AD[17]/100.0;
752   8   3:1   473   TO          := AD[18];
753   8   3:1   489   T1          := AD[19];
754   8   3:1   505   MOV         := AD[20];
755   8   3:1   521   MM          := AD[21];
756   8   3:1   537   CAE         := AD[22]/100.0;
757   8   3:1   559   CPLEL       := AD[23]/100.0;
758   8   3:1   581   TP          := AD[24];
759   8   3:1   597   CRP         := AD[26];
760   8   3:1   612   RUNNUM      := AD[27];
761   8   3:1   627   TCM         := AD[28];
762   8   3:1   643   NS          := TRUNC(AD[30]) - 1;
763   8   3:1   661
764   8   3:1   661   FOR I := 0 TO NS DO
765   8   3:2   679     BEGIN
766   8   3:3   679       SLVNM[I] := SG[17+I];
767   8   3:3   707       SLVWT[I] := AD[31+I]/100.0;
768   8   3:2   745     END;
769   8   3:2   757
770   8   3:1   757   MP          := AD[41];
771   8   3:1   773   CPP         := AD[42];
772   8   3:1   788   MC          := AD[43];
773   8   3:1   804   CPC         := AD[44];
774   8   3:1   819   FC[NG]      := AD[45]/1E6;
775   8   3:1   849   FC[OIL]     := AD[46]/1E6;
776   8   3:1   879   FC[PROPANE]:=AD[47]/1E6;
777   8   3:1   909   DE          := AD[48]/100.0;
778   8   3:1   933   PA          := AD[49]/100.0;
779   8   3:1   957   TA          := AD[50];
780   8   3:1   973   MSG         := AD[51];
781   8   3:1   989   EPC         := AD[52];
782   8   3:1  1005   PAN         := 1.0 - PA;
783   8   3:1  1022
784   8   3:1  1022   FOR I := 1 TO 2 DO
785   8   3:2  1038   BEGIN
786   8   3:3  1038     FOR J := 1 TO 6 DO
787   8   3:4  1049     BEGIN
788   8   3:5  1049       RPTDOL[I,J] := 0.0;
789   8   3:5  1080       RPTBTU[I,J] := 0.0;
790   8   3:4  1110     END;
791   8   3:2  1117   END;
```

```
8    3:2  1129
8    3:1  1129   IF T5 = 0 THEN
8    3:2  1140     IF SHRTYPE = 'BOILER'
8    3:2  1143       THEN T5 := 350.0
8    3:2  1159       ELSE IF SHRTYPE = 'PREHEAT' THEN T5 := 200.0;
8    3:2  1198
8    3:0  1198 END; (* INITDATA *)
8    3:0  1216
8    4:D     3 FUNCTION FUELT(S:STRING):FT;
8    4:0     0 BEGIN
8    4:1     0   FUELT := NG;
8    4:1     8   CASE S[1] OF
8    4:1    15     'N' : FUELT := NG;
8    4:1    20     'O' : FUELT := OIL;
8    4:1    25     'P' : FUELT := PROPANE;
8    4:1    30   END;
8    4:0    44 END;
8    4:0    56
8    4:0    56 (* SOLVENT.TEXT -- RETRIEVE CAV, DHVV, LELV, LHVV, *)
8    4:0    56 (* SVSV FOR ALL 0 TO NS SOLVENTS IN SLVNM[] WHICH  *)
8    4:0    56 (* MAY CONTAIN EITHER NAMES OR NUMBERS FOR         *)
8    4:0    56 (* DIRECT ACCESS                                   *)
8    4:0    56
8    5:D     1 PROCEDURE SOLDAT(BYNAME:STRING);
8    5:D    43
8    5:D    43 VAR SFILE : TEXT ;
8    5:D   344     NUMS  : INTEGER;
8    5:D   345     FND   : ARRAY[ST] OF BOOLEAN;
8    5:D   355     SNAME : STRING[30]; (* SOLVENT NAME *)
8    5:D   371     SANUM : INTEGER;  (* ACCESS NUMBER START WITH 1 *)
8    5:D   372     SCAV,SDHVV,SLELV,SLHVV,SSVSV : REAL;
8    5:D   382     I,J : INTEGER;
8    5:D   384     SOLFILE : STRING[30];
8    5:D   400
8    6:D     1 PROCEDURE MOVEREC(I:INTEGER; VAR J:INTEGER);
8    6:0     0 BEGIN
8    6:1     0     FND[I]  := TRUE;
8    6:1    12     CAV[I]  := SCAV;
8    6:1    29     DHVV[I] := SDHVV;
8    6:1    46     LELV[I] := SLELV;
8    6:1    63     LHVV[I] := SLHVV;
8    6:1    80     SVSV[I] := SSVSV;
8    6:1    97     J       := J + 1
8    6:0   100 END;
8    6:0   116
8    5:0     0 BEGIN  (* SOLDAT *)
8    5:0     0 (*$I-*)
8    5:1     0   SOLFILE := 'SOLDATA.TEXT';
8    5:1    37   REPEAT
8    5:2    37     IF LENGTH(SOLFILE) > 0
8    5:2    42     THEN BEGIN
8    5:4    46       IF (LENGTH(SOLFILE) < 6) OR
8    5:4    53          (COPY(SOLFILE,LENGTH(SOLFILE)-4,5)
8  5:4   73            <> '.TEXT')
8  5:4   83              THEN SOLFILE := CONCAT(SOLFILE,'.TEXT');
8  5:4  123       RESET(SFILE,SOLFILE);
8  5:4  133       SUCESSFUL := (IORESULT = 0);
8  5:4  140       IF NOT SUCESSFUL
8  5:4  140       THEN BEGIN
8  5:6  146         WRITELN(SOLFILE,' FILE NOT FOUND.');
8  5:6  188         WRITELN('REENTER SOLVENT FILE NAME. ');
8  5:6  231         READLN(SOLFILE);
8  5:5  247       END; (* NOT SUCESSFUL *)
8  5:3  247     END (* LENGTH(SOLFILE) > 0 *)
8  5:2  247     ELSE EXIT(PROGRAM); (* LENGTH(SOLFILE)=0 *)
8  5:1  253   UNTIL SUCESSFUL;
8  5:1  258
8  5:1  258   WRITELN;
8  5:1  264   WRITELN('SOLVENT DATA BEING READ.');
8  5:1  304   READLN(SFILE,SNAME);
8  5:1  318   READLN(SFILE,NUMS); (*1ST RECORD IS LENGTH *)
8  5:1  331   J := 0;
8  5:1  335   FOR I := 0 TO NS DO FND[I] := FALSE;
8  5:1  377   IF BYNAME = 'NAME'
8  5:1  379   THEN BEGIN
8  5:3  390     READLN(SFILE,SNAME);
8  5:3  404     READLN(SFILE,SANUM,
8  5:3  412           SCAV,SDHVV,SLELV,SLHVV,SSVSV);
8  5:3  457     WHILE (IORESULT=0) AND NOT EOF(SFILE)
8  5:3  468                     AND (J<=NS) DO
8  5:4  480       BEGIN
8  5:5  480         FOR I := 0 TO NS DO
8  5:6  499           IF NOT FND[I] AND (SLVNM[I] = SNAME)
8  5:6  528             THEN MOVEREC(I,J);
8  5:5  549         READLN(SFILE,SNAME);
8  5:5  563         READLN(SFILE,SANUM,
8  5:5  571                   SCAV,SDHVV,SLELV,SLHVV,SSVSV);
8  5:4  616       END; (* WHILE *)
8  5:2  618   END; (* IF BYNAME = 'NAME' *)
8  5:2  618
8  5:1  618   CLOSE(SFILE);
8  5:1  624
8  5:1  624   IF J < (NS+1) THEN
8  5:2  635     FOR I :=0 TO NS DO
8  5:3  654       IF NOT FND[I] THEN
8  5:4  669         WRITELN('SOLVENT ',SLVNM[I],' NOT FOUND');
8  5:0  741 END;  (* SOLDAT *)
8  5:0  776
8  7:D    1 PROCEDURE FINIT;
8  7:0    0 BEGIN
8  7:1    0   CAF[NG]       := 17.27;
8  7:1   18   CAF[OIL]      := 14.22;
8  7:1   36   CAF[PROPANE]  := 15.70;
8  7:1   54   HHVF[NG]      := 23879;
8  7:1   69   HHVF[OIL]     := 18933;
8  7:1   84   HHVF[PROPANE] := 21661;
```

```
898   8    7:1    99   LHVF[NG]        := 21520;
899   8    7:1   114   LHVF[OIL]       := 17862;
900   8    7:1   129   LHVF[PROPANE] := 19944;
901   8    7:1   144   FDCF[NG]        := 23.565;
902   8    7:1   162   FDCF[OIL]       := 0.133;
903   8    7:1   180   FDCF[PROPANE] := 0.236;
904   8    7:1   198   DCU[NG]         := 'SCF/HR';
905   8    7:1   218   DCU[OIL]        := 'GAL/HR';
906   8    7:1   238   DCU[PROPANE]  := 'GAL/HR';
907   8    7:0   258 END; (* FINIT *)
908   8    7:0   270
909   8    7:0   270
910   8    8:D     1 PROCEDURE INITLTAB;
911   8    8:D     1 VAR I : INTEGER;
912   8    8:0     0   BEGIN;
913   8    8:0     0   (* INITIALIZE TEMP/ENTHALPY DATA *)
914   8    8:1     0   LTAB[1,1] := 0;
915   8    8:1    23   LTAB[1,2] := 30;
916   8    8:1    46   LTAB[1,3] := 60;
917   8    8:1    69   LTAB[1,4] := 77;
918   8    8:1    92   FOR I := 1 TO 25 DO
919   8    8:2   103     LTAB[1,I+4] := I * 100;
920   8    8:1   137   LTAB[2,1] := -1.098;
921   8    8:1   165   LTAB[2,2] := -0.55;
922   8    8:1   193   LTAB[2,3] := 0;
923   8    8:1   216   LTAB[2,4] := 0.32;
924   8    8:1   244   LTAB[2,5] := 0.74;
925   8    8:1   272   LTAB[2,6] := 2.58;
926   8    8:1   300   LTAB[2,7] := 4.42;
927   8    8:1   328   LTAB[2,8] := 6.29;
928   8    8:1   356   LTAB[2,9] := 8.17;
929   8    8:1   384   LTAB[2,10] := 10.07;
930   8    8:1   412   LTAB[2,11] := 12.00;
931   8    8:1   440   LTAB[2,12] := 13.95;
932   8    8:1   468   LTAB[2,13] := 15.92;
933   8    8:1   496   LTAB[2,14] := 17.92;
934   8    8:1   524   LTAB[2,15] := 19.94;
935   8    8:1   552   LTAB[2,16] := 21.98;
936   8    8:1   580   LTAB[2,17] := 24.05;
937   8    8:1   608   LTAB[2,18] := 26.13;
938   8    8:1   636   LTAB[2,19] := 28.24;
939   8    8:1   664   LTAB[2,20] := 30.38;
940   8    8:1   692   LTAB[2,21] := 32.50;
941   8    8:1   720   LTAB[2,22] := 34.66;
942   8    8:1   748   LTAB[2,23] := 36.82;
943   8    8:1   776   LTAB[2,24] := 38.99;
944   8    8:1   804   LTAB[2,25] := 41.18;
945   8    8:1   832   LTAB[2,26] := 43.39;
946   8    8:1   860   LTAB[2,27] := 45.61;
947   8    8:1   888   LTAB[2,28] := 47.83;
948   8    8:1   916   LTAB[2,29] := 50.07;
949   8    8:1   944   (* CONVERT FROM BTU/SCF TO BTU/LB *)
950   8    8:1   944   FOR I := 1 TO LLT DO
```

```
 951   8    8:2   955      LTAB[2,I] := LTAB[2,I] * 13.089;
 952   8    8:0  1012 END; (* INITLTAB *)
 953   8    8:0  1028
 954   8    8:0  1028
 955   8    8:0  1028
 956   8    1:0     0 BEGIN(* INDATA *)
 957   8    1:0     0
 958   8    1:1     0   INITLTAB;
 959   8    1:1    14   FINIT;
 960   8    1:1    16   GOTOXY(0,0); CRT(ERASEOS);
 961   8    1:1    25   INITDATA;
 962   8    1:1    27   T2MAX := T2S;
 963   8    1:1    37   MO := 0;
 964   8    1:1    44   IF OVENEXIST THEN BEGIN
 965   8    1:3    48     OFUEL := FUELT(OVENFUEL);
 966   8    1:3    56     MO := 1.0 + (CAE+1.0) * CAF[OFUEL];
 967   8    1:2    93   END;
 968   8    1:1    93   MA := 0;
 969   8    1:1   100   MFA[1] := 0;
 970   8    1:1   115   IF ABEXIST THEN BEGIN
 971   8    1:3   120     AFUEL := FUELT(ABFUEL);
 972   8    1:3   130     MA := (CAE+1.0) * CAF[AFUEL];
 973   8    1:2   161   END;
 974   8    1:2   161
 975   8    1:1   161   SOLDAT('NAME'); (* RETRIEVE SOLVENT DATA *)
 976   8    1:1   170   MV[0] := CRP * SLVWT[0];
 977   8    1:1   197   MVSUM := 0;
 978   8    1:1   204   FOR I := 1 TO NS DO
 979   8    1:2   223     BEGIN
 980   8    1:3   223       MV[I] := CRP * SLVWT[I];
 981   8    1:3   254       MVSUM := MVSUM + MV[I];
 982   8    1:2   278     END;
 983   8    1:2   288
 984   8    1:1   288   LELMIN := 1;
 985   8    1:1   292   FOR I := 1 TO NS DO
 986   8    1:2   311     IF LELV[I] < LELV[LELMIN] THEN
 987   8    1:3   341       LELMIN := I;
 988   8    1:1   357   IF LELV[LELMIN] <= 0 THEN BEGIN
 989   8    1:3   376     WRITELN('MINIMUM LEL FOR ',SLVNM[LELMIN],
 990   8    1:3   420       ' IS ',LELV[LELMIN]:10:4);
 991   8    1:3   461     WRITELN(' IT MUST BE GREATER THAN ZERO')
 992   8    1:2   506   END;
 993   8    1:0   506 END; (* END SEGMENT INDATA *)
 994   8    1:0   530
 995   8    1:0   530 (*$P,IPROGS:INDATA.TEXT*)
 995   8    1:0   530 (*$P,IPROGS:VULCAN.TEXT*)
 996   8    1:0   530 (* VULCAN.TEXT *)
 997   8    1:0   530 (* 4 JUNE 1980 *)
 998   8    1:0   530 (*  10:40 A.M. *)
 999   8    1:0   530
1000   9    1:D     1 SEGMENT PROCEDURE VULCAN;
1001   9    1:D     1  VAR ITER,LOOP : BOOLEAN;
1002   9    1:D     3      TEMP      : REAL;
```

```
1003   9    1:D      5      LPCNT      : INTEGER;
1004   9    1:D      6
1005   9    1:D      6 (*************************************)
1006   9    1:D      6 (* THTOHT.TEXT -CONVERTS TEMP TO ENTHALPY AND REVERSE*)
1007   9    1:D      6
1008   9    2:D      3 FUNCTION LOOKUP(INP,OUT:INTEGER;TH:REAL):REAL;
1009   9    2:D      7 VAR FRAC : REAL;
1010   9    2:D      9     I, LO, HI : INTEGER;
1011   9    2:D     12     FOUND : BOOLEAN;
1012   9    2:D     13
1013   9    2:0      0 BEGIN

1014   9    2:1      0   HI := LLT;
1015   9    2:1      3   LO := 1;
1016   9    2:1      6   IF (TH>=LTAB[INP,LO]) AND (TH<=LTAB[INP,HI])
1017   9    2:1     60     THEN BEGIN
1018   9    2:3     63       FOUND := FALSE;
1019   9    2:3     66       WHILE (LO<=HI) AND NOT FOUND DO
1020   9    2:4     74       BEGIN
1021   9    2:5     74         I := (LO+HI) DIV 2;
1022   9    2:5     81         IF TH = LTAB[INP,I]
1023   9    2:5    104           THEN BEGIN
1024   9    2:7    110             LOOKUP := LTAB[OUT,I];
1025   9    2:7    135             FOUND := TRUE
1026   9    2:6    135           END
1027   9    2:5    138           ELSE IF TH < LTAB[INP,I]
1028   9    2:6    163                  THEN HI := I - 1
1029   9    2:6    170                  ELSE LO := I + 1;
1030   9    2:4    181       END; (* WHILE *)
1031   9    2:4    183
1032   9    2:3    183       IF NOT FOUND THEN BEGIN
1033   9    2:5    187         FRAC := (LTAB[INP,LO]-TH) /
1034   9    2:5    215                 (LTAB[INP,LO]-LTAB[INP,HI]);
1035   9    2:5    261         LOOKUP := LTAB[OUT,LO] -
1036   9    2:5    284                   FRAC*(LTAB[OUT,LO]-LTAB[OUT,HI])
1037   9    2:4    331       END;
1038   9    2:2    335     END
1039   9    2:1    335     ELSE BEGIN  (* OUT OF RANGE *)
1040   9    2:3    337       WRITELN('LOOKUP VALUE OUT OF RANGE ',TH,
1041   9    2:3    385               ' FOR ENTRY ',INP);
1042   9    2:3    420       LOOKUP := 0
1043   9    2:2    422     END;
1044   9    2:0    426 END; (* LOOKUP *)
1045   9    2:0    444
1046   9    2:0    444
1047   9    2:0    444 (* CONVERTS ENTHALPY TO TEMP *)
1048   9    3:D      3 FUNCTION HTOT(T:REAL):REAL;
1049   9    3:D      5 VAR TT : REAL;
1050   9    3:D      7
1051   9    3:0      0 BEGIN
1052   9    3:1      0   TT := LOOKUP(2,1,T);
1053   9    3:1     14   HTOT := TT;
1054   9    3:1     22   IF DEBUG THEN
1055   9    3:2     25     WRITELN('H[',T:8:2,'] = ',TT:6:1);
1056   9    3:0     81 END;
```

```
9    3:0    94
9    3:0    94 (* CONVERTS TEMP TO ENTHALPY *)
9    4:D     3 FUNCTION TTOH(T:REAL):REAL;
9    4:D     5 VAR TT : REAL;
9    4:D     7
9    4:0     0 BEGIN
9    4:1     0   TT := LOOKUP(1,2,T);
9    4:1    14   TTOH := TT;
9    4:1    22   IF DEBUG THEN
9    4:2    25     WRITELN('T[',T:6:1,'] = ',TT:8:2);
9    4:0    81 END;(* TTOHT *)
9    4:0    94
9    4:0    94 (**************************************)
9    4:0    94
9    5:D     1 PROCEDURE OVENINIT;
9    5:0     0  BEGIN
9    5:1     0   H[0] := TTOH(T0);
9    5:1    20   H[1] := TTOH(T1);
9    5:1    40   HA   := TTOH(TA);
9    5:1    54   H[5] := TTOH(T5);
9    5:1    74   HP   := TTOH(TP);
9    5:1    88   H60  := TTOH(60.0);
9    5:1   104   HR   := TTOH(TR);
9    5:1   118   HSTM := 1175.8;
9    5:1   130
9    5:1   130   LPCNT := 0;
9    5:1   134   LOOP := OPTIMIZE AND (ABTYPE = 'CATALYTIC');
9    5:1   157   ITER := FALSE;
9    5:1   161   T3[2] := 0.0;
9    5:1   180   IF TCM = 0.0
9    5:1   185     THEN TCM := T35;
9    5:0   206  END; (* OVENINIT *)
9    5:0   218
9    5:0   218 (**************************************)
9    5:0   218
9    6:D     3 FUNCTION PLELC(FLOWP,GASR : REAL) : REAL;
9    6:0     0  BEGIN (* PLELC *)
9    6:1     0    PLELC := (MVSUM * FLOWP * SVSV[LELMIN] * 100.0) /
9    6:1    33             (GASR * LELV[LELMIN] * 13.089);
9    6:0    62  END; (* PLELC *)
9    6:0    74
9    6:0    74 (**************************************)
9    6:0    74
9    6:0    74
9    7:D     1 PROCEDURE OVENS;
9    7:D     1 VAR MF1,MF2 : REAL;
9    7:D     5     SMV     : REAL;
9    7:D     7     I       : INTEGER;
9    7:D     8
9    7:0     0 BEGIN
9    7:1     0   IF TRACER THEN WRITELN('BEGINNING ',OVENTYPE,' OVEN');
9    7:1    53   IF OPTIMIZE AND NOT ITER
9    7:1    55     THEN BEGIN  (* OVEN OPTIMIZATION *)
```

```
9   7:3    62        MOV := PLELC(PAN,CPLEL);
9   7:3    80        IF MM > MOV THEN MOV := MM;
9   7:2   104      END
9   7:1   104      ELSE  (* NOT OPTIMIZATION *)
9   7:2   106        QLO := UO*AO*(T1-T0);
9   7:2   133
9   7:1   133    SMV := 0.0;
9   7:1   144    FOR I := 0 TO NS DO
9   7:2   157      SMV := SMV + MV[I] * DHVV[I];
9   7:1   196    SMV := SMV * PAN;
9   7:1   210
9   7:1   210    MFO := (MP*CPP + MC*CPC + UO*AO) *
9   7:1   245           (T1-T0) + SMV + MOV*(H[1]-H[0]);
9   7:1   294
9   7:1   294    IF OVENTYPE = 'ZONE'
9   7:1   296      THEN BEGIN
9   7:3   307        MF2 := LHVF[OFUEL];
9   7:3   323        MF1 := 0;
9   7:3   329        FOR I := 1 TO NS DO
9   7:4   342          MF1 := MF1 + MV[I] * LHVV[I];
9   7:3   381        MF1 := MF1 * PAN * DE * MR;
9   7:2   407      END
9   7:1   407      ELSE BEGIN
9   7:3   409        MF2 := LHVF[OFUEL] - MO*(H[1]+HP-2*H[0]);
9   7:3   464        MF1 := (MOV-MV[0]-MVSUM)*(HP-H[0])
9   7:2   506      END;
9   7:2   509
9   7:1   509    MFO := (MFO - MF1) / MF2;
9   7:1   529    ACO := MFO * HHVF[OFUEL] * FC[OFUEL] * AH;
9   7:1   570    PLEL := PLELC(PAN,MOV);
9   7:0   589 END; (* OVENS *)
9   7:0   606
9   7:0   606 (***************************************)
9   7:0   606
9   8:D     1 PROCEDURE MIXER;
9   8:D     1 VAR MFX: REAL;
9   8:0     0 BEGIN (* MIXER *)
9   8:1     0   IF TRACER THEN WRITELN('BEGINNING AUX GAS MIXER');
9   8:1    42   IF OVENTYPE = 'INTERNAL'
9   8:1    44     THEN MFX := MFO
9   8:1    61     ELSE MFX := MFO * MO * CAE;
9   8:1    90
9   8:1    90   MT := MOV + MSG + MFX;
9   8:1   111   H1R := ((MOV + MFX + PAN*MVSUM) * (H[1]-H60)
9   8:1   153          + (MSG + PA*MVSUM) * (HA-H60)) /
9   8:1   184            (MT + MVSUM + MFX)
9   8:1   200          + H60;
9   8:1   209   T1R := HTOT(H1R);
9   8:1   223   H[1] := H1R;
9   8:1   239   PLELA := PLELC(PA,MSG);
9   8:0   258 END;  (* MIXER *)
9   8:0   270
9   8:0   270 (***************************************)
```

```
 9   9:D    1 PROCEDURE ABMOD(AB:ABT);
 9   9:D    2  (* AB IS INDEX TO ACI,MFA,MFB,T2 *)
 9   9:D    2   VAR MF1,MF2  : REAL;
 9   9:D    6        I  : INTEGER;
 9   9:D    7
 9  10:D    1 PROCEDURE THERMAL;
 9  10:D    1
 9  10:D    1 VAR HJ,H2M : REAL;
 9  10:D    5
 9  10:0    0 BEGIN  (* THERMAL *)
 9  10:1    0    IF ABAIR = 'EXTERNAL'
 9  10:1    3      THEN HJ := H[0]
 9  10:1   29      ELSE HJ := H[2];
 9  10:1   50
 9  10:1   50   MFA[AB] := (MT-MVSUM-MF1) * (H[3]-H[2]) +
 9  10:1  104              UI*AI*(T3[AB]-T0) - MF2 +
 9  10:1  144              (MF1+MVSUM*DE) * (H[3]-HJ) -
 9  10:1  179              (HJ-H60) * MF1;
 9  10:1  198
 9  10:1  198   IF ABAIR = 'EXTERNAL'
 9  10:1  201     THEN BEGIN
 9  10:3  216       MFA[AB] := MFA[AB] / (LHVF[AFUEL] -
 9  10:3  257           (MA+1)*(H[3]-H[0]) + MA*(H[0]-H60));
 9  10:3  317      H2M := H[3] + (UI*AI*(T3[AB]-T0) - MF2 +
 9  10:3  369           MF1*(H[3]-2*H[0]+H60) +
 9  10:3  408           MVSUM*DE*(H[3]-H[0])) /
 9  10:3  444           (MT - MF1 - MVSUM)
 9  10:2  461     END
 9  10:1  465     ELSE BEGIN  (* INTERNAL *)
 9  10:3  467       MFA[AB] := MFA[AB] / (LHVF[AFUEL] -
 9  10:3  508           MA*(H[3]-H[2]) + CAF[AFUEL]*(H[3]-H60));
 9  10:3  573       H2M := (UI*AI*(T3[AB]-T0) +
 9  10:3  608           MT*H[3] - MF2 + H60*MF1) /
 9  10:3  644           (MT + MF1)
 9  10:2  655     END;
 9  10:2  658
 9  10:1  658   T2MAX := HTOT(H2M);
 9  10:1  671   QLI := UI * AI * (T3[AB]-T0);
 9  10:0  709 END; (* THERMAL *)
 9  10:0  726
 9  10:0  726 (*************************)
 9  11:D    1 PROCEDURE CATALYTC;
 9  11:D    1 VAR HJ1,HJ2,HJ3,CI1,CI2 : REAL;
 9  11:D   11     H2M,DELTAT,HRORCI : REAL;
 9  12:D    1  PROCEDURE SETUP;
 9  12:0    0   BEGIN
 9  12:1    0   IF ABAIR = 'EXTERNAL'
 9  12:1    3     THEN BEGIN
 9  12:3   18       CI1 := MFB[AB] * MA;
 9  12:3   44       CI2 := 1.0 + MA;
 9  12:3   62       HJ1 := H[0];
 9  12:3   78       HJ2 := H[0];
 9  12:3   94       HJ3 := H[0]
 9  12:2  106       END
 9  12:1  110       ELSE BEGIN
 9  12:3  112         CI1 := 0.0;
 9  12:3  124         CI2 := 1.0;
 9  12:3  136         HJ2 := HR;
 9  12:3  146         HJ3 := H[2]
 9  12:2  158       END;
 9  12:0  162   END; (*SETUP *)
 9  12:0  174
 9  13:D    1   PROCEDURE COMPMFB; (* COMPUTE AND RETURN MFB[AB] *)
 9  13:D    1     VAR MFBC : REAL;
 9  13:D    3         J : INTEGER;
 9  13:D    4         CONVG : BOOLEAN;
 9  13:0    0    BEGIN (* COMPMFB *)
 9  13:1    0     MFBC := MFB[AB];
 9  13:1   19     CONVG := FALSE;
 9  13:1   22     J := 0;
 9  13:1   25
 9  13:1   25     REPEAT
 9  13:2   25       MFB[AB] := (MFB[AB] + MFBC) /2.0;
 9  13:2   67       HCI := ((MT + MFB[AB] + CI1) * H[3] -
 9  13:2  109           MF2 + MF1 * (H60-H[0]) - H[0]*MVSUM*DE) /
 9  13:2  163           (MT + MFB[AB] - MVSUM + CI1);
 9  13:2  199       MFBC := (MF2 - MF1*(H60-H[0]) +
 9  13:2  230           MVSUM*(H[3]-HCI-DE*(H[3]-H[0]))
 9  13:2  282            - MT*(H[3]-HCI)) /
 9  13:2  308           (CI2 * (H[3]-HCI));
 9  13:2  334       CONVG := ABS((MFB[AB]-MFBC)/MFB[AB]) < 0.0001;
 9  13:2  382       J := J + 1;
 9  13:2  387       IF (J>20) AND NOT CONVG
 9  13:2  390         THEN WRITELN('DID NOT CONVERGE AFTER ',J,
 9  13:3  436                     ' ITERATIONS ',MFB[AB],MFBC);
 9  13:1  499    UNTIL CONVG OR (J>20);
 9  13:1  506
 9  13:0  506   END; (* COMPMFB *)
 9  13:0  520
 9  11:0    0 BEGIN  (* CATALYTC *)
 9  11:1    0   MFB[AB] := 0.01 * MT;
 9  11:1   28   SETUP;
 9  11:1   30
 9  11:1   30   COMPMFB; (* CONVERGE ON MFB *)
 9  11:1   32
 9  11:1   32   TCI := HTOT(HCI);
 9  11:1   46   IF TCI >= TR
 9  11:1   51     THEN BEGIN
 9  11:3   60       HRORCI := HCI;
 9  11:3   69       DELTAT := TCI - TO;
 9  11:3   84       IF ABAIR = 'INTERNAL' THEN HJ1 :=HCI;
 9  11:3  111       MFA[AB] := (MT*(HCI-H[2]) +
 9  11:3  147             UI*AI*DELTAT) /
 9  11:3  164             (LHVF[AFUEL]-HCI+H[0] +
 9  11:3  195             MA * (H[0]+HJ1-HCI-H60))
 9  11:2  230     END
```

```
1269   9   11:1   233     ELSE BEGIN
1270   9   11:3   235       HRORCI := HR;
1271   9   11:3   244       DELTAT := TR - TO;
1272   9   11:3   259       MFA[AB] := (MT*(HR-H[2]) +
1273   9   11:3   295             UI*AI*DELTAT) /
1274   9   11:3   312             (LHVF[AFUEL]-HR+H[0] +
1275   9   11:3   343             MA * (H[0]+HJ2-HR-H60));
1276   9   11:2   381     END;
1277   9   11:1   381   H3R := (MFA[AB]*(LHVF[AFUEL]-HCI+H[0]-
1278   9   11:1   430      MA*(HCI-H[0]+H60-HJ3))+MF2+
1279   9   11:1   472      (MF1+MVSUM*DE)*HRORCI +
1280   9   11:1   495      H[2]*(MT+MFA[AB]*CI2+MF1+MVSUM*DE))
1281   9   11:1   552      / (MT + MFA[AB]*CI2+MF1+MVSUM*DE*2);
1282   9   11:1   602   T3[AB] := HTOT(H3R);
1283   9   11:1   626   H[3] := H3R;
1284   9   11:1   642   QLI := UI * AI * DELTAT;
1285   9   11:1   663   H2M := (QLI / MT) + HRORCI;
1286   9   11:1   683   T2MAX := HTOT(H2M);
1287   9   11:0   696 END; (* CATALYTC *)
1288   9   11:0   712 (****************)
1289   9   11:0   712
1290   9    9:0     0 BEGIN (* ABMOD MAIN *)
1291   9    9:1     0   IF TRACER THEN
1292   9    9:2     3     WRITELN('BEGINNING ',ABTYPE,' AFTERBURNER');
1293   9    9:1    61   MF1 := 0.0;
1294   9    9:1    72   MF2 := 0.0;
1295   9    9:1    82   FOR I := 1 TO NS DO
1296   9    9:2    95     BEGIN
1297   9    9:3    95       MF1 := MF1 + MV[I] * CAV[I];
1298   9    9:3   127       MF2 := MF2 + MV[I] * LHVV[I]
1299   9    9:2   153     END;
1300   9    9:1   166   MF1 := DE * MF1;
1301   9    9:1   180   MF2 := DE * MF2;
1302   9    9:1   194
1303   9    9:1   194   IF ABTYPE = 'THERMAL'
1304   9    9:1   197     THEN THERMAL
1305   9    9:1   211     ELSE CATALYTC;
1306   9    9:1   217   ACI[AB] := MFA[AB] * HHVF[AFUEL] * FC[AFUEL] * AH;
1307   9    9:1   277   PLELR := PLELC(1.0,MT);
1308   9    9:0   297 END; (* AFTERBURNER MODULE *)
1309   9    9:0   312
1310   9    9:0   312
1311   9    9:0   312 (**************************************)
1312   9    9:0   312
1313   9   14:D     1 PROCEDURE PRIMHEAT;
1314   9   14:D     1 VAR MF1 : REAL;
1315   9   14:D     3     PH1,PH2 : REAL;
1316   9   14:D     7
1317   9   14:0     0 BEGIN
1318   9   14:1     0   IF TRACER THEN
1319   9   14:2     3     WRITELN('BEGINNING PRIMARY HEAT RECOVERY');
1320   9   14:1    50   IF ABAIR = 'EXTERNAL'
1321   9   14:1    53     THEN MF1 := MA
```

```
1322   9  14:1    70      ELSE MF1 := 0.0;
1323   9  14:1    90   H[4] := PX*(MT+MFA[1]*(1.0+MF1))*
1324   9  14:1   136             H[3] - MT*(H[2]-H[1]);
1325   9  14:1   180   H[4] := H[4] / (PX*(MT+MFA[1]*(1.0+MF1)));
1326   9  14:1   241   T4[2] := HTOT(H[4]);
1327   9  14:1   269   Q4 := (MT + MFA[1]*(1.0+MF1)) *
1328   9  14:1   303         ((1.0-PX)*H[3] + PX*H[4]);
1329   9  14:1   349   QPR := MT * (H[2]-H[1]);
1330   9  14:1   383   PH1 := PX * (MT + MFA[1]*(1.0 + MF1));
1331   9  14:1   424   PH2 := PH1 * (H[3]-H[4]);
1332   9  14:1   456   PHR := PH2 / (PH1 * H[3] - MT * H[1]);
1333   9  14:1   500   (*IF DEBUG THEN BEGIN
1334   9  14:1   500     WRITELN('MF1= ',MF1:10:4);
1335   9  14:1   500     WRITELN('H4= ',H[4]:8:2,' T4[2]= ',T4[2]:6:1);
1336   9  14:1   500     WRITELN('Q4= ',Q4:12:4,' QPR= ',QPR:12:2);
1337   9  14:1   500   END; *)
1338   9  14:0   500 END;  (* PRIMHEAT *)
1339   9  14:0   512
1340   9  14:0   512
1341   9  14:0   512 (****************************)
1342   9  15:D     1 PROCEDURE BOILER(AB:ABT);
1343   9  15:D     2 VAR  MF1 : REAL;
1344   9  15:D     4      FI  : FT;
1345   9  15:D     5
1346   9  15:0     0 BEGIN
1347   9  15:1     0   IF TRACER THEN
1348   9  15:2     3     WRITELN('BEGINNING WASTE HEAT BOILER');
1349   9  15:1    46   IF ABAIR = 'EXTERNAL' THEN MF1 := MA
1350   9  15:1    66                         ELSE MF1 := 0.0;
1351   9  15:1    86   QSR[AB] := (MT+MFA[AB]*(1+MF1)) * (H[4]-H[5]);
1352   9  15:1   150   MSTM[AB] := QSR[AB] / (HSTM - 168.0);
1353   9  15:1   190   AES[AB] := QSR[AB] * AH / 0.85;
1354   9  15:1   229   FOR FI := NG TO PROPANE DO
1355   9  15:2   240     WHBS[FI,AB] := FC[FI] * AES[AB];
1356   9  15:0   291 END;  (* BOILER *)
1357   9  15:0   306
1358   9  15:0   306 (****************************)
1359   9  16:D     1 PROCEDURE PREHEAT(AB:ABT);
1360   9  16:D     2  VAR N : INTEGER;
1361   9  16:D     3      MAXHO : REAL;
1362   9  16:0     0 BEGIN
1363   9  16:1     0   IF TRACER THEN
1364   9  16:2     3     WRITELN('BEGINNING OVEN AIR PREHEAT');
1365   9  16:1    45   N := 0;
1366   9  16:1    48   MAHO[AB] := MAH;
1367   9  16:1    66   MAXHO := H[1] + QLO/MOV;
1368   9  16:1    93   REPEAT
1369   9  16:2    93     N := N + 1;
1370   9  16:2    98     HOPRIME := (MAHO[AB]*MT*(H[4]-H[5]) +
1371   9  16:2   144         (MOV - MFO*MO) * H[0]) /
1372   9  16:2   174         (MOV - MFO*MO);
1373   9  16:2   194     IF HOPRIME > MAXHO
1374   9  16:2   199       THEN HOPRIME := MAXHO;
```

```
9  16:2  216       TOPRIME[AB] := HTOT(HOPRIME);
9  16:2  238       QSR[AB] := (MOV - MFO*MO) * (HOPRIME - H[0]);
9  16:2  286       MFR[AB] := MFO - (QSR[AB]/HHVF[OFUEL]);
9  16:2  331       MAHO[AB] := MFO * HHVF[OFUEL] / (MT * (H[4]-H[5]));
9  16:2  392       IF N < 2 THEN
9  16:3  397         IF MFR[AB] < 0.0
9  16:3  410           THEN BEGIN
9  16:5  420             MFR[AB] := 0.0;
9  16:5  440             RESC[AB] := FALSE;
9  16:4  453           END
9  16:3  453           ELSE
9  16:4  455             RESC[AB] := TRUE;
9  16:1  468   UNTIL RESC[AB] OR (N > 1);
9  16:1  486   IF ABS(MFR[AB]) < 0.001
9  16:1  500     THEN MFR[AB] := 0.0;
9  16:1  530   ACSIP[AB] := (QSR[AB]*HHVF[OFUEL]*FC[OFUEL]*AH) /
9  16:1  586           (LHVF[OFUEL]-MO*(H[1]-H[0]));
9  16:0  631 END;  (* PREHEAT *)
9  16:0  646
9  16:0  646 (*****************************)
9  17:D    1 PROCEDURE RECIRC(AB:ABT);
9  17:D    2 VAR MF1,MF2 : REAL;
9  17:D    6     MFT     : REAL;
9  17:D    8     SMV     : REAL;
9  17:D   10     HFA     : REAL;
9  17:D   12     I       : INTEGER;
9  17:D   13
9  17:0    0 BEGIN
9  17:1    0   IF TRACER THEN
9  17:2    3     WRITELN('BEGINNING OVEN RECIRCULATION');
9  17:1   47   SMV := 0.0;
9  17:1   58   FOR I := 0 TO NS DO
9  17:2   71     SMV := SMV + MV[I] * DHVV[I];
9  17:1  110   SMV := SMV * PAN;
9  17:1  124   MFT := (MP*CPP + MC*CPC + UO*AO) * (T1-T0)
9  17:1  169          + SMV + MOV*(H[1]-H[0])
9  17:1  203          -(MOV-PAN*(MV[0]+MVSUM))*(HP-H[0]);
9  17:1  255   MF2 := LHVF[OFUEL] - MO*(H[1]+HP-2.0*H[0]);
9  17:1  315   MF1 := - MT*MAH * (H[4]-H[0]);
9  17:1  355   MFR[AB] := (MFT + MF1) / MF2;
9  17:1  382   IF MFR[AB] < 0.0
9  17:1  395     THEN BEGIN
9  17:3  406       MFR[AB] := 0.0;
9  17:3  426       RESC[AB] := FALSE;
9  17:2  439     END
9  17:1  439     ELSE RESC[AB] := TRUE;
9  17:1  454   HFA := HHVF[OFUEL] * FC[OFUEL] * AH;
9  17:1  489   ACR[AB] := MFR[AB] * HFA;
9  17:1  520   QSR[AB] := MT*MAH * (H[4]-H[0]);
9  17:1  568   ACSIP[AB] := (MFO-MFR[AB]) * HFA;
9  17:1  605     (* COMPUTE OPTIMUM RECIRC TO OVEN *)
9  17:1  605   MAHO[AB] := MFT / (MT*(H[4]-H[2]));
9  17:0  652 END; (* RECIRC *)
```

```
1428  9  17:0  666
1429  9  17:0  666
1430  9  17:0  666
1431  9  18:D    1 PROCEDURE SHR(I:INTEGER);
1432  9  18:0    0 BEGIN
1433  9  18:1    0   H[4] := TTOH(T4[I]);
1434  9  18:1   28   CASE SHRTYPE[I] OF
1435  9  18:1   36     'B' : BOILER(I);
1436  9  18:1   44     'R' : RECIRC(I);
1437  9  18:1   52     'P' : PREHEAT(I);
1438  9  18:1   60   END;
1439  9  18:0  102 END; (* SHR *)
1440  9  18:0  114
1441  9  18:0  114 (************************************)
1442  9  18:0  114
1443  9   1:0    0 BEGIN (* VULCAN *)
1444  9   1:1    0   OVENINIT;
1445  9   1:1    2
1446  9   1:1    2   REPEAT
1447  9   1:2    2     IF OVENEXIST THEN OVENS;
1448  9   1:2    8
1449  9   1:2    8     IF MSEXIST THEN MIXER
1450  9   1:2   13       ELSE BEGIN
1451  9   1:4   17         MT := MOV;
1452  9   1:4   27         T1R := T1;
1453  9   1:3   37       END;
1454  9   1:3   37
1455  9   1:2   37     IF ABEXIST THEN
1456  9   1:3   42     BEGIN
1457  9   1:4   42       T3[1] := T3S;
1458  9   1:4   60       H[3] := TTOH(T3S);
1459  9   1:4   80       T2[1] := T1R;
1460  9   1:4   98       H[2] := H[1];
1461  9   1:4  120       ABMOD(1);
1462  9   1:4  126       T4[1] := T3[1];
1463  9   1:4  152       H[4] := H[3];
1464  9   1:4  174
1465  9   1:4  174       IF PEXIST THEN
1466  9   1:5  179       BEGIN
1467  9   1:6  179         IF T2MAX < T2S
1468  9   1:6  184           THEN T2[2] := T2MAX
1469  9   1:6  204           ELSE T2[2] := T2S;
1470  9   1:6  231         H[2] := TTOH(T2[2]);  (* COMPUTE ENTHALPY *)
1471  9   1:6  259         PRIMHEAT;
1472  9   1:6  261         (* COMPUTE AB WITH PREHEAT *)
1473  9   1:6  261         T3[2] := T3[1];
1474  9   1:6  287         ABMOD(2);
1475  9   1:5  293       END; (* PEXIST *)
1476  9   1:5  293
1477  9   1:3  293     END  (* ABEXIST *)
1478  9   1:2  293     ELSE BEGIN (* NO AB OR PRIMARY *)
1479  9   1:4  295       T4[1] := T1R;
1480  9   1:4  313       H[4] := H[1];
```

```
1481    9   1:4  335       LOOP := FALSE;
1482    9   1:3  338     END;
1483    9   1:3  338
1484    9   1:2  338     IF LOOP AND (LPCNT=0)
1485    9   1:2  342      THEN ITER := (T3[1]>TCM) OR (T3[2]>TCM);
1486    9   1:2  388
1487    9   1:2  388     IF ITER
1488    9   1:2  388       THEN BEGIN
1489    9   1:4  391         IF T3[1] > T3[2]
1490    9   1:4  415           THEN TEMP := T3[1]
1491    9   1:4  434           ELSE TEMP := T3[2];
1492    9   1:4  457         IF ABS(TEMP - TCM) <= 1.0
1493    9   1:4  468           THEN BEGIN (* CONVERGED *)
1494    9   1:6  478             ITER := FALSE;
1495    9   1:6  481             LOOP := FALSE;
1496    9   1:5  484           END
1497    9   1:4  484           ELSE BEGIN (* ADJUST AIR FLOW *)
1498    9   1:6  486             MOV := MOV * (1.0 + 20.0*(TEMP-TCM)/TCM);
1499    9   1:6  527             IF TRACER THEN BEGIN
1500    9   1:8  530               WRITELN('ITERATION ',LPCNT);
1501    9   1:8  564               WRITELN(' AIR FLOW = ',MOV:10:2);
1502    9   1:8  605               WRITELN(' T3[1] = ',T3[1]:7:1,' T3[2] =
',T3[2]:7:1);
1503    9   1:7  691             END;
1504    9   1:5  691           END;
1505    9   1:3  691       END; (* IF ITER *)
1506    9   1:3  691
1507    9   1:2  691     LPCNT := LPCNT + 1;
1508    9   1:2  696     IF LOOP AND (LPCNT>20)
1509    9   1:2  700       THEN WRITELN(' DID NOT CONVERGE');
1510    9   1:1  736   UNTIL NOT LOOP OR (LPCNT > 20);
1511    9   1:1  744
1512    9   1:1  744   IF SEXIST THEN
1513    9   1:2  749   BEGIN
1514    9   1:3  749     H[1] := TTOH(T1);
1515    9   1:3  769     SHR(1);
1516    9   1:3  772     IF PEXIST THEN SHR(2);
1517    9   1:2  780   END; (* SECONDARY HEAT RECOVERY *)
1518    9   1:2  780
1519    9   1:0  780 END; (* VULCAN *)
1520    9   1:0  802
1521    9   1:0  802
1522    9   1:0  802 (*$P,IPROGS:VULCAN.TEXT*)
1522    9   1:0  802 (*$P,IPROGS:REPORT.TEXT*)
1523    9   1:0  802 (* REPORT.TEXT *)
1524    9   1:0  802 (*  3 JUNE  80 *)
1525    9   1:0  802 (*   3:15 P.M. *)
1526   10   1:D    1 SEGMENT PROCEDURE REPORT;
1527   10   1:D    1 CONST F1 = 38;
1528   10   1:D    1       F4 = 14;
1529   10   1:D    1       F5 =  4;
1530   10   1:D    1       DEGF = 'DEG-F';
1531   10   1:D    1       LBHR = 'LB/HR';
```

```
10   1:D     1        BTUSCF = 'BTU/SCF';
10   1:D     1        MMBTU = '(MM BTU)/HR';
10   1:D     1        DPYR = '$/YR';
10   1:D     1        BTUYR = '(MM BTU)/YR';
10   1:D     1        BL = '
10   1:D     1
10   1:D     1 VAR PF : INTERACTIVE;
10   1:D   302     H1:STRING[50];
10   1:D   328     H2:STRING[20];
10   1:D   339     I,J:INTEGER;
10   1:D   341     FUELNAM:ARRAY[FT] OF STRING[14];
10   1:D   365     TMPBTU:ARRAY[1..2,1..6] OF REAL;
10   1:D   389     TMPDOL:ARRAY[1..2,1..6] OF REAL;
10   1:D   413     FF : CHAR;  (* FORM FEED *)
10   1:D   414     LF : CHAR;  (* LINE FEED *)
10   1:D   415     CH : CHAR;  (* TEMP *)
10   1:D   416     HOLD : BOOLEAN; (* HOLD FOR CONSOLE *)
10   1:D   417     TFC  : REAL;  (* TOTAL FUEL COSTS *)
10   1:D   419
10   1:D   419 (************************************)
10   2:D     1 PROCEDURE HEADING;
10   2:0     0 BEGIN
10   2:1     0   REPEAT
10   2:2     0     WRITELN;
10   2:2     6     WRITELN('ENTER DEVICE NAME [PRINTER:,REMOUT:] ');
10   2:2    59     WRITELN;
10   2:2    65     READLN(DEVICE);
10   2:1    80   UNTIL IORESULT=0;
10   2:1    86   IF DEVICE = '' THEN DEVICE := 'CONSOLE:';
10   2:1   110   RESET(PF,DEVICE);
10   2:0   120 END; (* HEADING *)
10   2:0   134
10   2:0   134 (* PAUSE IF DISPLAY IS ON CONSOLE: *)
10   3:D     1 PROCEDURE WAITER;
10   3:0     0 BEGIN
10   3:1     0   IF HOLD THEN BEGIN
10   3:3     6     WRITELN;
10   3:3    12     WRITE('ENTER SPACE TO CONTINUE >>');
10   3:3    48     READ(CH);
10   3:3    58     WRITELN;
10   3:2    64   END;
10   3:0    64 END; (* WAITER *)
10   3:0    76
10   4:D     3 FUNCTION ROUNDER(R:REAL):REAL;
10   4:D     5  CONST SF = 16384.0;
10   4:D     5  VAR V : REAL;
10   4:D     7      S,I : INTEGER;
10   4:0     0 BEGIN
10   4:1     0   V := R / SF;
10   4:1    15   IF V < MAXINT
10   4:1    19   THEN BEGIN
10   4:3    27     S := TRUNC(V);
10   4:3    35     V := S * SF;
```

```
1585  10    4:3    48      I := ROUND(R - V);
1586  10    4:3    61      ROUNDER := I + V;
1587  10    4:2    72    END
1588  10    4:1    72    ELSE ROUNDER := R;
1589  10    4:0    82 END;
1590  10    4:0    94
1591  10    5:D     3 FUNCTION RJUST(V:REAL;F2,F3:INTEGER):INTEGER;
1592  10    5:D     7 VAR M:INTEGER;
1593  10    5:0     0 BEGIN
1594  10    5:0     0   (* IF V >= 0 THEN M:=1
1595  10    5:0     0                ELSE M:=2; *)
1596  10    5:1     0   RJUST:= F4-(F2-F3); (* M NOT ADDED *)
1597  10    5:0     7 END;  (* RJUST *)
1598  10    5:0    20
1599  10    6:D     3 FUNCTION LJUST(F2:INTEGER):INTEGER;
1600  10    6:0     0 BEGIN
1601  10    6:1     0   LJUST := F5 - F2 + 1;
1602  10    6:0     7 END;  (* LJUST *)
1603  10    6:0    20
1604  10    7:D     1 PROCEDURE PLR(V:REAL; F2,F3:INTEGER);
1605  10    7:D     5 VAR L,R:INTEGER;
1606  10    7:0     0 BEGIN
1607  10    7:1     0   R:=RJUST(V,F2,F3);
1608  10    7:1    12   L:=LJUST(F3);
1609  10    7:1    19   WRITELN(PF,H1,BL:F1-LENGTH(H1)+R,
1610  10    7:1    92           V:F2:F3,BL:L,H2);
1611  10    7:0   174 END;  (* PLR *)
1612  10    7:0   186
1613  10    8:D     1 PROCEDURE PLI(V,F2:INTEGER);
1614  10    8:D     3 VAR L,R:INTEGER;
1615  10    8:0     0 BEGIN
1616  10    8:1     0   R:=RJUST(V,F2,-1);
1617  10    8:1    11   L:=LJUST(-1);
1618  10    8:1    19   WRITELN(PF,H1,BL:F1-LENGTH(H1)+R,
1619  10    8:1    92           V:F2,BL:L,H2);
1620  10    8:0   170 END;  (* PLI *)
1621  10    8:0   182
1622  10    9:D     1 PROCEDURE PLS(V:STRING);
1623  10    9:0     0 BEGIN
1624  10    9:1     0   WRITELN(PF,H1,BL:F1-LENGTH(H1),
1625  10    9:1    76           V,' ',H2);
1626  10    9:0   110 END; (* PLS *)
1627  10    9:0   122
1628  10   10:D     1 PROCEDURE SPACE(M:INTEGER);
1629  10   10:0     0 BEGIN
1630  10   10:1     0   FOR I := 1 TO M DO
1631  10   10:2    16     WRITELN(PF);
1632  10   10:0    34 END;
1633  10   10:0    48
1634  10   11:D     1 PROCEDURE CENTER(V:STRING);
1635  10   11:D    43 VAR J:INTEGER;
1636  10   11:0     0 BEGIN
1637  10   11:1     0   J:=TRUNC(40.0-LENGTH(V)/2.0);
```

```
10   11:1    29    WRITELN(PF,BL:J,V);
10   11:0    98  END; (* CENTER *)
10   11:0   110
10   11:0   110  (***************************************************)
10   11:0   110
10   12:D     1  PROCEDURE GETSUMVAL;
10   12:D     1  VAR K,J:INTEGER;
10   12:D     3
10   13:D     1  PROCEDURE GETRPT;
10   13:0     0  BEGIN
10   13:1     0    IF OVENEXIST THEN
10   13:2     4    BEGIN
10   13:3     4      RPTBTU[J,1] := ACO/(FC[OFUEL]*1E6);
10   13:3    52      RPTDOL[J,1] := ACO;
10   13:2    79    END;
10   13:1    79    IF ABEXIST THEN
10   13:2    84      BEGIN
10   13:3    84        RPTBTU[J,2] := ACI[1]/(FC[AFUEL]*1E6);
10   13:3   142        RPTDOL[J,2] := ACI[1];
10   13:2   178      END;
10   13:2   178
10   13:1   178    RPTBTU[J,3] := RPTBTU[J,1]+RPTBTU[J,2];
10   13:1   248    RPTDOL[J,3] := RPTDOL[J,1]+RPTDOL[J,2];
10   13:1   318    TFC := RPTDOL[J,3];
10   13:1   347
10   13:1   347    IF ABEXIST AND PEXIST THEN
10   13:2   356      BEGIN
10   13:3   356        RPTDOL[J,4] := ACO+ACI[2];
10   13:3   397        RPTBTU[J,4] := RPTBTU[J,1]+ACI[2]/(FC[AFUEL]*1E6);
10   13:3   479        TFC := RPTDOL[J,4];
10   13:2   508      END;
10   13:1   508    IF SEXIST THEN
10   13:2   513    BEGIN
10   13:3   513      RPTBTU[J,5] := RPTBTU[J,3]-AH*QSR[1]/1E6;
10   13:3   586      RPTDOL[J,5] := RPTBTU[J,5]*FC[OFUEL]*1E6;
10   13:3   653      IF PEXIST THEN
10   13:4   658        BEGIN
10   13:5   658          RPTBTU[J,6] := RPTBTU[J,4]-AH*QSR[2]/1E6;
10   13:5   732          RPTDOL[J,6] := RPTBTU[J,6]*FC[OFUEL]*1E6;
10   13:5   799          TFC := RPTDOL[J,6];
10   13:4   828        END
10   13:3   828        ELSE IF RPTDOL[J,5] < TFC THEN
10   13:5   863               TFC := RPTDOL[J,5];
10   13:2   892    END;
10   13:0   892  END; (* GETRPT *)
10   13:0   910
10   14:D     1  PROCEDURE GETTMP;
10   14:D     1  VAR L : INTEGER;
10   14:0     0  BEGIN
10   14:1     0    FOR K := 1 TO 6 DO
10   14:2    14    BEGIN
10   14:3    14      FOR L := 1 TO 2 DO
10   14:4    25      BEGIN
```

```
1691  10   14:5    25        TMPDOL[L,K] := 0.0;
1692  10   14:5    56        TMPBTU[L,K] := 0.0;
1693  10   14:4    86      END;
1694  10   14:3    93      IF K > 3 THEN
1695  10   14:4   100      BEGIN
1696  10   14:5   100        TMPBTU[1,K] := RPTBTU[J,3]-RPTBTU[J,K];
1697  10   14:5   173        TMPDOL[1,K] := RPTDOL[J,3]-RPTDOL[J,K]
1698  10   14:4   241      END
1699  10   14:3   246      ELSE BEGIN
1700  10   14:5   248        TMPDOL[1,K] := 0.0;
1701  10   14:5   278        TMPBTU[1,K] := 0.0;
1702  10   14:4   308      END;
1703  10   14:3   308      IF OPTIMIZE THEN
1704  10   14:4   312      BEGIN
1705  10   14:5   312        TMPDOL[2,K] := RPTDOL[1,K]-RPTDOL[2,K];
1706  10   14:5   383        TMPBTU[2,K] := RPTBTU[1,K]-RPTBTU[2,K];
1707  10   14:4   454      END;
1708  10   14:2   454    END;
1709  10   14:0   464 END; (* GETTMP *)
1710  10   14:0   486
1711  10   12:0     0 BEGIN  (* GETSUMVAL *)
1712  10   12:1     0   IF OPTIMIZE THEN J := 2
1713  10   12:1     4               ELSE J := 1;
1714  10   12:1    12   GETRPT;
1715  10   12:1    14   GETTMP;
1716  10   12:0    16 END; (* GETSUMVAL *)
1717  10   12:0    28
1718  10   12:0    28 (*******************************************************)
1719  10   12:0    28
1720  10   15:D     1 PROCEDURE SUMMARY;
1721  10   15:D     1 VAR CONFIG:ARRAY[1..6] OF STRING[20];
1722  10   15:D    67     CONFIG1,CONFIG2,CONFIGPL:STRING[6];
1723  10   15:D    79     J,K:INTEGER;
1724  10   15:D    81
1725  10   16:D     1 PROCEDURE HEADER;
1726  10   16:D     1
1727  10   16:D     1  VAR K,DASH:INTEGER;
1728  10   16:D     3      OIAS,COM,EPM,NOPT,VOCD,SAF,OAF,AAS,
1729  10   16:D     3      ECO,SCF,AS,COF,DBT,MMB : STRING;
1730  10   16:D   577
1731  10   17:D     1  PROCEDURE FILLUP;
1732  10   17:0     0   BEGIN
1733  10   17:1     0     OIAS := 'OVEN/INCINERATOR ANALYSIS SUMMARY';
1734  10   17:1    42     COM  := '(CONTROLLED OVEN MODE)';
1735  10   17:1    73     EPM  := '(EXISTING PLANT MODE)';
1736  10   17:1   103     NOPT := '          NON-OPTIMIZATION';
1737  10   17:1   136     VOCD := 'VOC DESTRUCTION EFF';
1738  10   17:1   164     SAF  := 'SYSTEM AIR FLOW:      ';
1739  10   17:1   194     OAF  := 'OVEN AIR FLOW:        ';
1740  10   17:1   224     AAS  := 'ANNUAL           ANNUAL SAVINGS';
1741  10   17:1   263     ECO  := 'ENERGY     COST             OVER';
1742  10   17:1   302     SCF  := ' SCFM';
1743  10   17:1   316     AS   := '       ANNUAL SAVINGS';
```

```
1744  10   17:1   344      COF   := '   CONFIGURATION      (MM BTU)';
1745  10   17:1   381      DBT   := '    ($)     (MM BTU)     ($)';
1746  10   17:1   416      MMB   := '     (MM BTU)     ($)';
1747  10   17:1   444
1748  10   17:0   444    END; (* FILLUP *)
1749  10   17:0   456
1750  10   18:D     3   FUNCTION LBTOSCF(X:REAL) : REAL;
1751  10   18:D     5   (* CONVERT LBS TO SCFM *)
1752  10   18:0     0   BEGIN
1753  10   18:1     0     LBTOSCF := X * 13.089 / 60.0;
1754  10   18:0    23   END;  (* LBTOSCF *)
1755  10   18:0    36
1756  10   16:0     0 BEGIN
1757  10   16:1     0    FILLUP; (* FILL IN STRINGS *)
1758  10   16:1     2    WAITER;
1759  10   16:1     4    SPACE(5);
1760  10   16:1     7    CENTER(OIAS);
1761  10   16:1    12    IF OPTIMIZE
1762  10   16:1    12      THEN H1 := COM
1763  10   16:1    20      ELSE H1 := EPM;
1764  10   16:1    36    CENTER(H1);
1765  10   16:1    42    SPACE(1);
1766  10   16:1    45    WRITELN(PF,BL:22,SAF,LBTOSCF(MT):10:2,SCF);
1767  10   16:1   141    WRITELN(PF,BL:22,OAF,LBTOSCF(MOV):10:2,SCF);
1768  10   16:1   237    WRITELN(PF,BL:22,'OVEN PLEL',PLEL*100:21:2,' %');
1769  10   16:1   343    WRITELN(PF,BL:22,VOCD,DE*100:10:1,'  %');
1770  10   16:1   441    SPACE(1);
1771  10   16:1   444    WAITER;
1772  10   16:1   446    WRITE(PF,BL:27,AAS);
1773  10   16:1   509    IF OPTIMIZE THEN WRITELN(PF,AS)
1774  10   16:1   528                 ELSE WRITELN(PF);
1775  10   16:1   536    WRITE(PF,BL:22,ECO);
1776  10   16:1   599    IF OPTIMIZE THEN WRITELN(PF,BL:16,'OVER')
1777  10   16:1   676                 ELSE WRITELN(PF);
1778  10   16:1   684    WRITE(PF,BL:23,'USED',BL:19,'OVN+INCIN');
1779  10   16:1   823    IF OPTIMIZE THEN WRITELN(PF,NOPT)
1780  10   16:1   843                 ELSE WRITELN(PF);
1781  10   16:1   851    WRITE(PF,COF);
1782  10   16:1   860    WRITE(PF,DBT);
1783  10   16:1   869    IF OPTIMIZE THEN WRITELN(PF,MMB)
1784  10   16:1   888                 ELSE WRITELN(PF);
1785  10   16:1   896    IF OPTIMIZE THEN DASH := 80
1786  10   16:1   900                 ELSE DASH := 60;
1787  10   16:1   908
1788  10   16:1   908    FOR K := 1 TO DASH DO
1789  10   16:2   922      WRITE(PF,'-');
1790  10   16:1   937    WRITELN(PF);
1791  10   16:0   943    END; (* HEADER *)
1792  10   16:0   958
1793  10   19:D     1 PROCEDURE BODY;
1794  10   19:D     1 VAR I:INTEGER;
1795  10   19:D     2
1796  10   20:D     1 PROCEDURE TABLINE(I:INTEGER);
```

```
10   20:0     0 BEGIN
10   20:1     0   WRITE(PF,CONFIG[I],BL:20-LENGTH(CONFIG[I]));
10   20:1    85   WRITE(PF,RPTBTU[J,I]:10:2,RPTDOL[J,I]:10:2);
10   20:1   147   WRITE(PF,TMPBTU[1,I]:10:2,TMPDOL[1,I]:10:2);
10   20:1   207   IF OPTIMIZE
10   20:1   207     THEN WRITELN(PF,TMPBTU[2,I]:10:2,TMPDOL[2,I]:10:2)
10   20:1   277     ELSE WRITELN(PF);
10   20:1   285   IF NOT HOLD THEN SPACE(1);
10   20:0   295 END; (* TABLINE *)
10   20:0   308
10   21:D     1 PROCEDURE FCOST;
10   21:0     0 BEGIN (* FCOST *)
10   21:1     0   WAITER;
10   21:1     2   SPACE(2);
10   21:1     5   CENTER('SUMMARY OF FUEL COST SAVINGS');
10   21:1    38   SPACE(1);
10   21:1    41   WRITELN(PF,'EXISTING PLANT CONFIGURATION');
10   21:1    85   H1 := '  ANNUAL FUEL COSTS';
10   21:1   113   H2 := DPYR;
10   21:1   126   IF EPC = 0 THEN PLR(ROUNDER(RPTDOL[1,1]),12,1)
10   21:1   164     ELSE PLR(ROUNDER(EPC),12,1);
10   21:1   181   WRITELN(PF,'CONTROLLED OVEN WITH VOC CONTROL AND');
10   21:1   233   H1 := '  HEAT RECOVERY, ANNUAL FUEL COSTS';
10   21:1   276   PLR(ROUNDER(TFC),12,1);
10   21:1   290   H1 := 'TOTAL FUEL SAVINGS';
10   21:1   317   IF EPC = 0 THEN PLR(ROUNDER(RPTDOL[1,1]-TFC),12,1)
10   21:1   362     ELSE PLR(ROUNDER(EPC-TFC),12,1);
10   21:1   386   H1 := 'PRIMARY HEAT RECOVERED';
10   21:1   417   H2 := BTUYR;
10   21:1   437   PLR(QPR*AH/1E6,12,2);
10   21:1   459   H1 := 'SECONDARY HEAT RECOVERED';
10   21:1   492   PLR(QSR[2]*AH/1E6,12,2);
10   21:1   523   SPACE(2);
10   21:0   526 END;  (* FCOST *)
10   21:0   538
10   19:0     0 BEGIN  (* BODY *)
10   19:1     0   SPACE(1);
10   19:1     3   IF OVENEXIST THEN TABLINE(1);
10   19:1    10   IF ABEXIST THEN TABLINE(2);
10   19:1    18   IF OVENEXIST AND ABEXIST THEN TABLINE(3);
10   19:1    29   IF PEXIST THEN TABLINE(4);
10   19:1    37   IF SEXIST THEN
10   19:2    42   BEGIN
10   19:3    42     TABLINE(5);
10   19:3    45     IF PEXIST THEN TABLINE(6);
10   19:2    53   END;
10   19:1    53   IF OPTIMIZE THEN FCOST; (* PRINT FUEL SAVINGS *)
10   19:0    59 END; (* BODY *)
10   19:0    72
10   22:D     1 PROCEDURE CREDITS;
10   22:0     0 BEGIN
10   22:1     0   CENTER('THIS ANALYSIS MODEL WAS DEVELOPED BY:');
10   22:1    42   CENTER('CENTEC CORPORATION');
```

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 1850  10   22:1    65   CENTER('RESTON, VIRGINIA');
 1851  10   22:1    86   CENTER('AND');
 1852  10   22:1    94   CENTER('FT. LAUDERDALE, FLORIDA');
 1853  10   22:1   122   SPACE(2);
 1854  10   22:1   125   CENTER('PLEASE DIRECT QUESTIONS CONCERNING THE');
 1855  10   22:1   168   CENTER('ANALYSIS TO:  MR. TERENCE KARDA        ');
 1856  10   22:1   211 ' CENTER('                   305/491-6660        ');
 1857  10   22:1   254   WAITER;
 1858  10   22:1   256   IF NOT HOLD THEN WRITELN(PF,FF);
 1859  10   22:0   280 END; (* CREDITS *)
 1860  10   22:0   292
 1861  10   15:0     0 BEGIN (* SUMMARY *)
 1862  10   15:1     0   IF OPTIMIZE THEN J := 2
 1863  10   15:1     4               ELSE J := 1;
 1864  10   15:1    12   IF OVENEXIST THEN CONFIG1 := 'OVN'
 1865  10   15:1    18                ELSE CONFIG1 := '';
 1866  10   15:1    35   IF ABEXIST THEN CONFIG2 := 'INCIN'
 1867  10   15:1    42              ELSE CONFIG2 := '';
 1868  10   15:1    61   IF OVENEXIST AND ABEXIST THEN CONFIGPL := '+'
 1869  10   15:1    71                           ELSE CONFIGPL := '';
 1870  10   15:1    83   CONFIG[1] := 'OVN ALONE';
 1871  10   15:1   107   CONFIG[2] := 'INCIN ALONE';
 1872  10   15:1   133   CONFIG[3] := '';
 1873  10   15:1   148   CONFIG[4] := '+PRIM';
 1874  10   15:1   168   CONFIG[5] := '+SEC';
 1875  10   15:1   187   CONFIG[6] := '+PRIM+SEC';
 1876  10   15:1   211   FOR K := 3 TO 6 DO
 1877  10   15:2   224     CONFIG[K] := CON-
CAT(CONFIG1,CONFIGPL,CONFIG2,CONFIG[K]);
 1878  10   15:1   291   HEADER;
 1879  10   15:1   293   BODY;
 1880  10   15:1   295   CREDITS;
 1881  10   15:0   297 END; (* SUMMARY *)
 1882  10   15:0   312
 1883  10   15:0   312 (****************************************************)
 1884  10   15:0   312
 1885  10   23:D     1 PROCEDURE GENERAL;
 1886  10   23:D     1 VAR IFL:FT;
 1887  10   23:0     0   BEGIN
 1888  10   23:1     0     H1:='OVEN-INCINERATOR DESIGN MODEL';
 1889  10   23:1    38     SPACE(5);
 1890  10   23:1    41     CENTER(H1);
 1891  10   23:1    47     IF OPTIMIZE
 1892  10   23:1    47       THEN H1:='(CONTROLLED OVEN MODE)'
 1893  10   23:1    55       ELSE H1:='(EXISTING PLANT MODE)';
 1894  10   23:1   114     CENTER(H1);
 1895  10   23:1   120     H1:='*** GENERAL INFORMATION ***';
 1896  10   23:1   156     SPACE(1);
 1897  10   23:1   159     CENTER(H1);
 1898  10   23:1   165     SPACE(1);
 1899  10   23:1   168     H2:='';
 1900  10   23:1   177     H1:='PLANT NAME:';
 1901  10   23:1   197     PLS(PLNAME);
```

```
1902  10   23:1   201    H1:='PROCESS DESCRIPTION:';
1903  10   23:1   230    PLS(PROCESS);
1904  10   23:1   234    H1:='PRODUCT DESCRIPTION:';
1905  10   23:1   263    PLS(DESCRP);
1906  10   23:1   267    H1:='DATE:';
1907  10   23:1   281    PLS(SYSDATE);
1908  10   23:1   285    H1:='INPUT FILE NAME:';
1909  10   23:1   310    PLS(FILEIN);
1910  10   23:1   314    H1:='RUN NUMBER';
1911  10   23:1   333    PLR(RUNNUM,6,2);
1912  10   23:1   341    H1:='ANNUAL OPERATING HOURS';
1913  10   23:1   372    H2:='HRS/YR';
1914  10   23:1   387    PLR(AH,10,1);
1915  10   23:1   396    H1:='SYSTEM GAS FLOW RATE';
1916  10   23:1   425    H2:=LBHR;
1917  10   23:1   439    PLR(MT,12,1);
1918  10   23:1   443    H1:=' ';
1919  10   23:1   455    H2:='SCFM';
1920  10   23:1   468    PLR(MT*13.089/60,12,1);
1921  10   23:1   488    H1:='COATING RATE';
1922  10   23:1   509    H2:=LBHR;
1923  10   23:1   523    PLI(ROUND(CRP),9);
1924  10   23:1   532    H1:='VOC DESTRUCTION EFF';
1925  10   23:1   560    H2:='%';
1926  10   23:1   567    PLR(DE*100,8,1);
1927  10   23:1   579    SPACE(1);
1928  10   23:1   582    H1:='* SOLVENT DATA *';
1929  10   23:1   607    CENTER(H1);
1930  10   23:1   613    SPACE(1);
1931  10   23:1   616    WRITELN(PF,'SOLVENT NAME',
1932  10   23:1   633                      'MIXTURE':28,
1933  10   23:1   655                      'OVEN REMOVAL RATE':20,
1934  10   23:1   682                      'AUX REMOVAL RATE':20);
1935  10   23:1   714    WRITELN(PF,'(%)':38,
1936  10   23:1   727                      '(LBS/HR)':17,
1937  10   23:1   745                      '(LBS/HR)':21);
1938  10   23:1   769    FOR I:=0 TO NS DO
1939  10   23:2   787      IF SLVWT[I] > 0 THEN
1940  10   23:3   807        WRITELN(PF,SLVNM[I],BL:33-LENGTH(SLVNM[I]),
1941  10   23:3   894                        SLVWT[I]*100:6:2,'      ',
1942  10   23:3   934                        MV[I]*PAN:10:2,BL:11,
1943  10   23:3  1015                        MV[I]*PA:10:2);
1944  10   23:1  1061    SPACE(1);
1945  10   23:1  1064    H1:='* FUEL COSTS *';
1946  10   23:1  1087    CENTER(H1);
1947  10   23:1  1093    SPACE(1);
1948  10   23:1  1096    H2:='$/(MM BTU)';
1949  10   23:1  1115    FOR IFL:=NG TO PROPANE DO
1950  10   23:2  1126    BEGIN
1951  10   23:3  1126      H1:=FUELNAM[IFL];
1952  10   23:3  1142      PLR(FC[IFL]*1E6,10,2);
1953  10   23:2  1165    END;
1954  10   23:1  1172    SPACE(1);
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1955  10   23:0  1175   END; (* GENERAL *)
1956  10   23:0  1196
1957  10   23:0  1196 (************************************************************)
1958  10   23:0  1196
1959  10   24:D     1   PROCEDURE OVEN;
1960  10   24:0     0   BEGIN
1961  10   24:1     0     WAITER;
1962  10   24:1     2     H1:='*** CURING OVEN ***';
1963  10   24:1    30     SPACE(1);
1964  10   24:1    33     CENTER(H1);
1965  10   24:1    39     SPACE(1);
1966  10   24:1    42     H2:='';
1967  10   24:1    51     H1:='OVEN TYPE';
1968  10   24:1    69     PLS(OVENTYPE);
1969  10   24:1    73     H1:='FUEL';
1970  10   24:1    86     PLS(OVENFUEL);
1971  10   24:1    90     H1:='OVEN GAS FLOW RATE';
1972  10   24:1   117     H2:=LBHR;
1973  10   24:1   131     PLR(MOV,12,1);
1974  10   24:1   140     H1:=' ';
1975  10   24:1   147     H2:='SCFM';
1976  10   24:1   160     PLR(MOV*13.089/60,12,1);
1977  10   24:1   180     H1:='COMBUSTION AIR SOURCE';
1978  10   24:1   210     H2:=' ';
1979  10   24:1   217     PLS(OVENAIR);
1980  10   24:1   221     H1:='INLET AIR TEMPERATURE,TO';
1981  10   24:1   254     H2:=DEGF;
1982  10   24:1   268     PLI(ROUND(TO),8);
1983  10   24:1   278     H1:='EXHAUST AIR TEMPERATURE,T1';
1984  10   24:1   313     PLI(ROUND(T1),8);
1985  10   24:1   323     H1:='PREHEAT AIR TEMPERATURE,TP';
1986  10   24:1   358     PLI(ROUND(TP),8);
1987  10   24:1   368     H1:='EXCESS COMBUSTION AIR';
1988  10   24:1   398     H2:='%';
1989  10   24:1   405     PLR(CAE*100,6,2);
1990  10   24:1   416     H1:='GASES RECYCLED';
1991  10   24:1   439     PLR(MR*100,6,2);
1992  10   24:1   451     IF (MC > 0) THEN
1993  10   24:2   462     BEGIN
1994  10   24:3   462       H1:='SPECIFIC HEAT OF CONVEYOR';
1995  10   24:3   496       H2:='BTU/LB DEG-F';
1996  10   24:3   517       PLR(CPC,12,2);
1997  10   24:3   525       H1:='CONVEYOR MASS FLOW RATE';
1998  10   24:3   557       H2:=LBHR;
1999  10   24:3   571       PLR(MC,12,2);
2000  10   24:2   580     END;
2001  10   24:1   580     IF MP > 0 THEN
2002  10   24:2   591     BEGIN
2003  10   24:3   591       H1:='SPECIFIC HEAT OF PRODUCT';
2004  10   24:3   624       H2:='BTU/LB DEG-F';
2005  10   24:3   645       PLR(CPP,12,2);
2006  10   24:3   653       H1:='PRODUCT MASS FLOW RATE';
2007  10   24:3   684       H2:=LBHR;
```

```
10    24:3    698       PLR(MP,12,2);
10    24:2    707     END;
10    24:1    707     H1:='OVEN SURFACE AREA';
10    24:1    733     H2:='SQ-FT';
10    24:1    747     PLR(AO,12,2);
10    24:1    755     H1:='RADIATION HEAT TRANSFER COEFFICIENT';
10    24:1    799     H2:='BTU/(SQ-FT DEG-F HR)';
10    24:1    828     PLR(UO,12,2);
10    24:1    837     H1:='PERCENT OF LEL';
10    24:1    860     H2:='%';
10    24:1    867     PLR(PLEL*100,6,2);
10    24:1    879     H1:='RADIATION HEAT LOSS';
10    24:1    907     H2:=MMBTU;
10    24:1    927     PLR(QLO/1E6,10,4);
10    24:1    943     H1:='FUEL MASS FLOW RATE';
10    24:1    971     H2:=LBHR;
10    24:1    985     PLR(MFO,12,2);
10    24:1    994     H1:=' ';
10    24:1   1001     H2:=MMBTU;
10    24:1   1021     PLR(MFO*HHVF[OFUEL]/1E6,10,4);
10    24:1   1051     H2:=DCU[OFUEL];
10    24:1   1067     PLR(MFO*FDCF[OFUEL],15,4);
10    24:1   1089     H1:='ANNUAL COST';
10    24:1   1109     H2:=DPYR;
10    24:1   1122     PLR(ROUNDER(ACO),12,1);
10    24:0   1134   END;  (* OVEN REPORT *)
10    24:0   1146
10    24:0   1146 (****************************************************)
10    25:D      1   PROCEDURE MIXMOD;
10    25:0      0   BEGIN (* MIXMOD *)
10    25:1      0     WAITER;
10    25:1      2     SPACE(1);
10    25:1      5     H1:='*** AUXILIARY GAS MIXER ***';
10    25:1     41     CENTER(H1);
10    25:1     47     SPACE(1);
10    25:1     50     H1:='FLOW FROM AUXILIARY GAS SOURCE';
10    25:1     89     H2:='%';
10    25:1     96     PLR(PA*100,6,2);
10    25:1    108     H1:='EXHAUST TEMP FROM AUX STATION,TA';
10    25:1    149     H2:=DEGF;
10    25:1    163     PLI(ROUND(TA),8);
10    25:1    173     H1:='MASS FLOW RATE OF AUX GAS';
10    25:1    207     H2:=LBHR;
10    25:1    221     PLR(MSG,12,2);
10    25:1    230     H1:=' ';
10    25:1    237     H2:='SCFM';
10    25:1    250     PLR(MSG*13.089/60,12,1);
10    25:1    270     H1 := 'PLEL OF AUXILIARY GAS SOURCE';
10    25:1    307     H2 := '%';
10    25:1    314     PLR(PLELA*100.0,6,2);
10    25:1    331     H1:='MIXER EXHAUST AIR TEMP,T1R';
10    25:1    366     H2:=DEGF;
10    25:1    380     PLI(ROUND(T1R),8);
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10   25:0   390   END; (* MIXMOD *)
10   25:0   402
10   25:0   402 (*****************************************************)
10   25:0   402
10   26:D     1   PROCEDURE ABURNER;
10   26:0     0   BEGIN
10   26:1     0     WAITER;
10   26:1     2     SPACE(1);
10   26:1     5     H1:='*** AFTERBURNER ***';
10   26:1    33     CENTER(H1);
10   26:1    39     SPACE(1);
10   26:1    42     H1:='AFTERBURNER TYPE';
10   26:1    67     H2:='';
10   26:1    76     PLS(ABTYPE);
10   26:1    81     H1:='FUEL TYPE';
10   26:1    99     PLS(ABFUEL);
10   26:1   104     H1:='COMBUSTION AIR SOURCE';
10   26:1   134     PLS(ABAIR);
10   26:1   139     H1:='EXCESS COMBUSTION AIR';
10   26:1   169     H2:='%';
10   26:1   176     PLR(CAE*100,12,2);
10   26:1   187     H1:='SURFACE AREA';
10   26:1   208     H2:='SQ-FT';
10   26:1   222     PLR(AI,12,2);
10   26:1   231     H1:='RADIATION HEAT TRANSFER COEFFICIENT';
10   26:1   275     H2:='BTU/(SQ-FT DEG-F HR)';
10   26:1   304     PLR(UI,12,2);
10   26:1   313     H1:='INLET TEMPERATURE,T2';
10   26:1   342     H2:=DEGF;
10   26:1   356     PLI(ROUND(T2[1]),10);
10   26:1   374     H1 := 'PLEL OF INLET FLOW';
10   26:1   401     H2 := '%';
10   26:1   408     PLR(PLELR*100.0,6,2);
10   26:1   425     H1:='EXHAUST TEMPERATURE,T3';
10   26:1   456     PLI(ROUND(T3[1]),10);
10   26:1   474     H1:='MAXIMUM INLET TEMPERATURE,T2M';
10   26:1   512     H2:=DEGF;
10   26:1   526     PLR(T2MAX,12,2);
10   26:1   535     IF T3[1] <> T3S THEN
10   26:2   557     BEGIN
10   26:3   557       H1:='SPECIFIED EXHAUST TEMPERATURE,T3';
10   26:3   598       H2:=DEGF;
10   26:3   612       PLI(ROUND(T3S),10);
10   26:2   622     END;
10   26:1   622     IF ABTYPE = 'CATALYTIC' THEN
10   26:2   641     BEGIN
10   26:3   641       H1 := 'MAXIMUM EXHAUST TEMP,TCM';
10   26:3   674       H2 := 'DEG-F';
10   26:3   688       PLR(ROUND(TCM),12,2);
10   26:3   700       H1 := 'CATALYTIC REACTIVITY TEMP,TR';
10   26:3   737       H2 := DEGF;
10   26:3   751       PLI(ROUND(TR),10);
10   26:3   761       IF TCI > TR THEN
```

```
10   26:4    775       BEGIN
10   26:5    775         H1 :='CALTALYST INLET TEMP,TCI';
10   26:5    808         PLI(ROUND(TCI),10);
10   26:4    818       END;
10   26:2    818     END;
10   26:1    818     H1:='FUEL MASS FLOW RATE';
10   26:1    846     H2:=LBHR;
10   26:1    860     PLR(MFA[1],12,2);
10   26:1    877     H1:=' ';
10   26:1    884     H2:=MMBTU;
10   26:1    904     PLR(MFA[1]*HHVF[AFUEL]/1E6,10,4);
10   26:1    943     H2:=DCU[AFUEL];
10   26:1    960     PLR(MFA[1]*FDCF[AFUEL],12,2);
10   26:1    991     H1:='RADIATION HEAT LOSS';
10   26:1   1019     H2:=MMBTU;
10   26:1   1039     PLR(QLI/1E6,10,4);
10   26:1   1055     H1:='ANNUAL COST';
10   26:1   1075     H2:=DPYR;
10   26:1   1088     PLR(ROUNDER(ACI[1]),12,1);
10   26:0   1109   END;  (* ABURNER *)
10   26:0   1124
10   26:0   1124  (*****************************************************)
10   26:0   1124
10   27:D      1   PROCEDURE PRIMHEAT;
10   27:D      1   VAR QPR1:REAL;
10   27:0      0   BEGIN
10   27:1      0     WAITER;
10   27:1      2     SPACE(1);
10   27:1      5     H1:='*** PRIMARY HEAT RECOVERY ***';
10   27:1     43     CENTER(H1);
10   27:1     49     SPACE(1);
10   27:1     52     H1:='TYPE PRIMARY HEAT RECOVERY UNIT';
10   27:1     92     H2:='';
10   27:1    101     (* PLS(PRIMTYPE); *)
10   27:1    101     H1:='PERCENT EXHAUST GAS USED';
10   27:1    134     H2:='%';
10   27:1    141     PLR(PX*100,8,2);
10   27:1    153     H1:='INLET TEMPERATURE TO PRIMARY,T3';
10   27:1    193     H2:=DEGF;
10   27:1    207     PLI(ROUND(T3[1]),10);
10   27:1    225     H1:='EXHAUST TEMPERATURE FROM PRIMARY,T4';
10   27:1    269     PLI(ROUND(T4[2]),10);
10   27:1    287     H1:='HEAT RECOVERED IN PRIMARY';
10   27:1    321     H2:=MMBTU;
10   27:1    341     PLR(QPR/1E6,10,3);
10   27:1    357     H1:='MAX HEAT AVAIL. FOR SECOND. RECOVERY';
10   27:1    402     PLR(Q4/1E6,12,3);
10   27:1    419     H1:='ANNUAL SAVINGS FROM PRIMARY';
10   27:1    455     H2:=DPYR;
10   27:1    468     QPR1:=ACI[1]-ACI[2];
10   27:1    499     PLR(ROUNDER(QPR1),12,1);
10   27:1    511     H1:='PERCENT HEAT RECOVERED';
10   27:1    542     H2:='%';
```

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10   27:1   549      PLR(PHR*100.0,6,2);
10   27:0   565    END; (* PRIMHEAT *)
10   27:0   578
10   27:0   578 (***************************************************)
10   27:0   578
10   28:D     1    PROCEDURE ABPRIM;
10   28:0     0    BEGIN
10   28:1     0      WAITER;
10   28:1     2      SPACE(1);
10   28:1     5      H1:='*** AFTERBURNER WITH PRIMARY HEAT RECOVERY ***';
10   28:1    60      CENTER(H1);
10   28:1    66      SPACE(1);
10   28:1    69      H1:='INLET TEMPERATURE FROM PRIMARY,T2';
10   28:1   111      H2:=DEGF;
10   28:1   125      PLR(T2[2],10,2);
10   28:1   142      H1:='FUEL MASS FLOW RATE';
10   28:1   170      H2:=LBHR;
10   28:1   184      PLR(MFA[2],12,2);
10   28:1   201      H1:=' ';
10   28:1   208      H2:=MMBTU;
10   28:1   228      PLR(MFA[2]*HHVF[AFUEL]/1E6,10,4);
10   28:1   267      H2:=DCU[AFUEL];
10   28:1   284      PLR(MFA[2]*FDCF[AFUEL],12,2);
10   28:1   315      H1:='EXHAUST TEMPERATURE,T3';
10   28:1   346      H2:=DEGF;
10   28:1   360      PLI(ROUND(T3[2]),10);
10   28:1   378      IF T3[2] <> T3S THEN
10   28:2   400      BEGIN
10   28:3   400        H1:='SPECIFIED EXHAUST TEMPERATURE,T3';
10   28:3   441        H2:=DEGF;
10   28:3   455        PLI(ROUND(T3S),10);
10   28:2   465      END;
10   28:1   465      H1:='RADIATION HEAT LOSS';
10   28:1   493      H2:=MMBTU;
10   28:1   513      PLR(QLI/1E6,10,4);
10   28:1   529      H1:='ANNUAL COST';
10   28:1   549      H2:=DPYR;
10   28:1   562      PLR(ROUNDER(ACI[2]),12,1);
10   28:0   583    END;  (* ABPRIM *)
10   28:0   596
10   28:0   596 (****************************************************)
10   28:0   596
10   29:D     1    PROCEDURE PRIMSEC(IPS:INTEGER);
10   29:D     2    VAR IFL:FT;
10   29:D     3        SX : STRING[1];
10   29:D     4
10   30:D     1     PROCEDURE RMFUEL;
10   30:0     0     BEGIN
10   30:1     0       IF RESC[IPS]
10   30:1    13         THEN BEGIN
10   30:3    16           H1:='RECYCLED AIR TO OVEN';
10   30:3    45           H2:='%';
10   30:3    52           PLR(MAH*100,5,1);
```

```
 2220  10   30:3    64          H1:=' ';
 2221  10   30:3    71          H2:=LBHR;
 2222  10   30:3    85          PLR(MAH*MOV,10,1);
 2223  10   30:2   100        END;
 2224  10   30:1   100     H1 := 'OPTIMUM % AIR RECIRCULATED TO OVEN';
 2225  10   30:1   143     H2 := '%';
 2226  10   30:1   150     PLR(MAHO[IPS]*100,5,1);
 2227  10   30:1   172     H1:='REVISED FUEL MASS FLOW RATE';
 2228  10   30:1   208     H2:=LBHR;
 2229  10   30:1   222     PLR(MFR[IPS],12,2);
 2230  10   30:1   241     H1:=' ';
 2231  10   30:1   248     H2:=MMBTU;
 2232  10   30:1   268     PLR(MFR[IPS]*HHVF[OFUEL]/1E6,10,4);
 2233  10   30:1   307     H2:=DCU[OFUEL];
 2234  10   30:1   323     PLR(MFR[IPS]*FDCF[OFUEL],12,2);
 2235  10   30:1   355     H1:='ANNUAL OVEN FUEL SAVED';
 2236  10   30:1   386     H2:=DPYR;
 2237  10   30:1   399     PLR(ROUNDER(ACSIP[IPS]),12,2);
 2238  10   30:0   422   END; (* RMFUEL *)
 2239  10   30:0   434
 2240  10   29:0     0  BEGIN
 2241  10   29:1     0    WAITER;
 2242  10   29:1     2    SPACE(1);
 2243  10   29:1     5    IF IPS = 2
 2244  10   29:1     6      THEN H1:='*** SECONDARY AND PRIMARY HEAT RECOVERY
***'
 2245  10   29:1    14
 2246  10   29:1   104      ELSE H1:='*** SECONDARY HEAT RECOVERY ***';
 2247  10   29:1   110    CENTER(H1);
 2248  10   29:1   110
 2249  10   29:1   118    CASE SHRTYPE[1] OF
 2250  10   29:3   118    'B': BEGIN  (* BOILER *)
 2251  10   29:3   144         H1 := 'WASTE HEAT BOILER';
 2252  10   29:3   150         CENTER(H1);
 2253  10   29:3   153         SPACE(1);
 2254  10   29:3   185         H1:='MASS FLOW RATE OF STEAM';
 2255  10   29:3   199         H2:=LBHR;
 2256  10   29:3   216         PLR(MSTM[IPS],12,2);
 2257  10   29:3   244         H1:='ANNUAL ENERGY SAVED';
 2258  10   29:3   259         H2:='MM BTU';
 2259  10   29:3   283         PLR(AES[IPS]/1E6,12,4);
 2260  10   29:3   296         H2 := DPYR;
 2261  10   29:3   332         WRITELN(PF,'SAVINGS BY FUEL TYPE');
 2262  10   29:4   343         FOR IFL := NG TO OIL DO
 2263  10   29:5   343         BEGIN
 2264  10   29:5   359           H1:=FUELNAM[IFL];
 2265  10   29:4   382           PLR(WHBS[IFL,IPS],12,2);
 2266  10   29:2   389         END;
 2267  10   29:2   391      END;  (* CASE OF BOILER *)
 2268  10   29:1   391
 2269  10   29:3   391    'R': BEGIN  (* RECIRC *)
 2270  10   29:3   425         H1 := 'AIR RECIRCULATION TO OVEN';
 2271  10   29:3   431         CENTER(H1);
                              SPACE(1);
```

```
2272  10   29:3   434           RMFUEL;
2273  10   29:3   436           H1:='REVISED ANNUAL COST';
2274  10   29:3   464           H2:=DPYR;
2275  10   29:3   477           PLR(ROUNDER(ACR[IPS]),12,1);
2276  10   29:2   498         END;  (* CASE OF RECIRC *)
2277  10   29:2   500
2278  10   29:1   500       'P':BEGIN  (* PREHEAT *)
2279  10   29:3   500           H1 := 'OVEN INLET AIR PREHEAT';
2280  10   29:3   531           CENTER(H1);
2281  10   29:3   537           SPACE(1);
2282  10   29:3   540           H1:='REVISED OVEN INLET TEMPERATURE';
2283  10   29:3   579           H2:=DEGF;
2284  10   29:3   593           PLI(ROUND(TOPRIME[IPS]),10);
2285  10   29:3   611           RMFUEL;
2286  10   29:2   613         END;  (* CASE OF PREHEAT *)
2287  10   29:1   615     END;  (* CASE OF *)
2288  10   29:1   656     SX := ' ';
2289  10   29:1   661     SX[1] := CHR(48+2+IPS);
2290  10   29:1   671     H1:=CONCAT('INLET TEMPERATURE,T',SX);
2291  10   29:1   718     H2:=DEGF;
2292  10   29:1   732     PLI(ROUND(T4[IPS]),10);
2293  10   29:1   750     IF SHRTYPE[1] <> 'R' THEN
2294  10   29:2   760     BEGIN
2295  10   29:3   760       H1 := 'EXHAUST TEMPERATURE,T5';
2296  10   29:3   791       PLI(ROUND(T5),10);
2297  10   29:2   801     END;
2298  10   29:1   801     H1:='HEAT RECOVERED IN SECONDARY';
2299  10   29:1   837     H2:=MMBTU;
2300  10   29:1   857     PLR(QSR[IPS]/1E6,12,2);
2301  10   29:0   881 END;  (* PRIMSEC *)
2302  10   29:0   900
2303  10   29:0   900 (*****************************************************
2304  10   29:0   900
2305  10    1:0     0 BEGIN  (* REPORT *)
2306  10    1:1     0   LF := CHR(10);
2307  10    1:1    13   FF := CHR(12);
2308  10    1:1    17   GETSUMVAL;
2309  10    1:1    19   WRITELN;
2310  10    1:1    25   WRITE('DO YOU WANT A HARD COPY REPORT? ');
2311  10    1:1    67   IF YES THEN BEGIN
2312  10    1:3    74     FUELNAM[NG]  := '  NATURAL GAS';
2313  10    1:3   101     FUELNAM[OIL] := '  OIL';
2314  10    1:3   120     FUELNAM[PROPANE] := '  PROPANE';
2315  10    1:3   143     IF (DEVICE = '') OR (DEVICE = 'CONSOLE:')
2316  10    1:3   165       THEN HEADING
2317  10    1:3   168       ELSE RESET(PF,DEVICE);
2318  10    1:3   181     HOLD := (DEVICE = 'CONSOLE:');
2319  10    1:3   199     WRITE('DO YOU WANT ONLY A SUMMARY? ');
2320  10    1:3   237     IF NOT YES THEN BEGIN
2321  10    1:5   245       GENERAL;
2322  10    1:5   247       IF OVENEXIST THEN OVEN;
2323  10    1:5   253       IF NOT HOLD THEN WRITELN(PF,FF,LF,LF,LF,LF);
2324  10    1:5   309       IF MSEXIST THEN MIXMOD;
```

```
2325  10   1:5  316        IF ABEXIST THEN ABURNER;
2326  10   1:5  323        IF PEXIST THEN PRIMHEAT;
2327  10   1:5  330        IF ABEXIST AND PEXIST THEN ABPRIM;
2328  10   1:5  341        IF MSEXIST AND PEXIST  AND SEXIST AND NOT HOLD
2329  10   1:5  352          THEN WRITELN(PF,FF,LF,LF,LF,LF);
2330  10   1:5  409        IF SEXIST THEN PRIMSEC(1);
2331  10   1:5  417        IF SEXIST AND PEXIST THEN PRIMSEC(2);
2332  10   1:5  429        IF NOT HOLD THEN WRITELN(PF,FF,LF,LF,LF,LF);
2333  10   1:4  485      END;
2334  10   1:3  485      SUMMARY;
2335  10   1:3  487      CLOSE(PF);
2336  10   1:2  493    END;
2337  10   1:0  493 END;  (* REPORT *)
2338  10   1:0  516
2339  10   1:0  516 (*$P,IPROGS:REPORT.TEXT*)
2339  10   1:0  516 (*$P,IPROGS:CHARSUBS.TEXT*)
2340  10   1:0  516 (* CHARSUBS.TEXT *)
2341  10   1:0  516 (* UPDATED  27 MAR 1980 *)
2342  10   1:0  516 (* 12:35 P.M. *)
2343  10   1:0  516
2344   1   3:D    1 PROCEDURE CRT (* (C: CRTCOMMAND) *) ;
2345   1   3:D    2 (*******************************************************)
2346   1   3:D    2 (*CRT COMMANDS ARE: ERASEOS,ERASEOL,UP,DOWN,RIGHT,LEFT*)
2347   1   3:D    2 (*******************************************************)
2348   1   3:0    0 BEGIN
2349   1   3:1    0   IF PREFIXED[C] THEN
2350   1   3:2   11     UNITWRITE(1,CRTINFO[LEADIN],1,0,12);
2351   1   3:1   23   UNITWRITE(1,CRTINFO[C],1,0,12);
2352   1   3:0   35 END;
2353   1   3:0   48
2354   1   3:0   48
2355   1   2:D    1 PROCEDURE PROMPTAT (* (Y: INTEGER; S: STRING) *);
2356   1   2:0    0 BEGIN
2357   1   2:1    0   GOTOXY(0,Y);
2358   1   2:1   10   WRITE(S);
2359   1   2:1   19   CRT(ERASEOL);
2360   1   2:0   22 END;
2361   1   2:0   34
2362   1   2:0   34
2363   1   6:D    3 FUNCTION GETCHAR(OKSET: SETOFCHAR): CHAR;
2364   1   6:D   19 (*******************************************************)
2365   1   6:D   19 (*GET A CHARACTER, BEEP IF NOT IN OKSET,               *)
2366   1   6:D   19 (*      ECHO ONLY IF PRINTING                          *)
2367   1   6:D   19 (*******************************************************)
2368   1   6:D   19 VAR CH: CHAR;
2369   1   6:D   20     GOOD: BOOLEAN;
2370   1   6:0    0 BEGIN
2371   1   6:1    0   REPEAT
2372   1   6:2    0     READ(KEYBOARD,CH);
2373   1   6:2    8     IF EOLN(KEYBOARD) THEN CH:=CHR(13);
2374   1   6:2   21     GOOD:= CH IN OKSET;
2375   1   6:2   31     IF NOT GOOD THEN WRITE(CHR(7))
2376   1   6:2   44       ELSE IF CH IN [' '..'↑'] THEN WRITE(CH);
```

```
 1    6:1     79   UNTIL GOOD;
 1    6:1     83   GETCHAR:=CH;
 1    6:0     87 END; (* GETCHAR *)
 1    6:0    102
 1    6:0    102 (*
 1    6:0    102 PROCEDURE GETSTRING(VAR S: STRING; MAXLEN: INTEGER);
 1    6:0    102  *)
 1    6:0    102 (**************************************************)
 1    6:0    102 (*  GET AND ECHO A STRING UP TO MAXLEN CHARS LONG.  *)
 1    6:0    102 (*  IF NULL STRING ENTERED,                         *)
 1    6:0    102 (*        DEFAULT AND PRINT PREVIOUS VALUE.         *)
 1    6:0    102 (**************************************************)
 1    6:0    102   (*
 1    6:0    102 VAR S1: STRING[1];
 1    6:0    102     STEMP: STRING[80];
 1    6:0    102     OKSET: SET OF CHAR;
 1    6:0    102     BS,CR: SET OF CHAR;
 1    6:0    102 BEGIN
 1    6:0    102   OKSET:=[' '..'↑'];
 1    6:0    102   BS := [CHR(8)];
 1    6:0    102   CR := [CHR(13)];
 1    6:0    102   S1:=' ';
 1    6:0    102   STEMP:='';
 1    6:0    102   REPEAT
 1    6:0    102     IF LENGTH(STEMP) = 0
 1    6:0    102       THEN S1[1]:=GETCHAR(OKSET + CR)
 1    6:0    102       ELSE IF LENGTH(STEMP)=MAXLEN
 1    6:0    102               THEN S1[1]:=GETCHAR(CR + BS)
 1    6:0    102               ELSE S1[1]:=GETCHAR(OKSET + CR + BS);
 1    6:0    102     IF S1[1] IN OKSET THEN STEMP:=CONCAT(STEMP,S1)
 1    6:0    102       ELSE IF S1[1]=CHR(8) THEN
 1    6:0    102         BEGIN
 1    6:0    102           CRT(LEFT); WRITE(' '); CRT(LEFT);
 1    6:0    102           DELETE(STEMP,LENGTH(STEMP),1);
 1    6:0    102         END;
 1    6:0    102   UNTIL S1[1] = CHR(13);
 1    6:0    102
 1    6:0    102   IF LENGTH(STEMP) <> 0 THEN S:=STEMP
 1    6:0    102   ELSE WRITE(S);
 1    6:0    102 END; *) (* GETSTRING *)
 1    6:0    102
 1    4:D      3 FUNCTION YES (* : BOOLEAN *);
 1    4:0      0 BEGIN
 1    4:1      0   YES:= GETCHAR(['Y','y','N','n']) IN ['Y','y'];
 1    4:1     48   WRITELN;
 1    4:0     54 END; (* YES *)
 1    4:0     66
 1    5:D      3 FUNCTION RVAL (* (S:STRING):REAL *) ;
 1    5:D     45 VAR I,J,L,M,V,ISGN:INTEGER;
 1    5:D     51     K,N,F,G: REAL;
 1    5:0      0 BEGIN
 2428    1     5:1      0   L := LENGTH(S);
 2429    1     5:1     11   K := 0; F := 0;
 2430    1     5:1    = 1; M:=1;
 2431    1     5:1     29   IF L > 0 THEN BEGIN
 2432    1     5:3     35     IF S[1] = '-'
 2433    1     5:3     40       THEN BEGIN ISGN:=-1;M:=2; END;
 2434    1     5:3     51     J := POS('.',S);
 2435    1     5:3     64     IF J = 0 THEN J := L + 1;
 2436    1     5:3     76     IF M < J THEN
 2437    1     5:4     83       FOR I := M TO J-1 DO
 2438    1     5:5    100         IF S[I] IN NUMBER
 2439    1     5:5    106           THEN K := K*10.0 + ORD(S[I]) - ORD('0');
 2440    1     5:3    150     M := J + 1;
 2441    1     5:3    156     IF M <= L THEN
 2442    1     5:4    163     BEGIN
 2443    1     5:5    163       N := 1;
 2444    1     5:5    169       FOR I := M TO L DO
 2445    1     5:6    184         IF S[I] IN NUMBER
 2446    1     5:6    190           THEN BEGIN
 2447    1     5:8    199             F := F*10.0 + ORD(S[I]) - ORD('0');
 2448    1     5:8    226             N := N * 10.0;
 2449    1     5:7    241           END;
 2450    1     5:5    249       F := F / N;
 2451    1     5:4    262     END;
 2452    1     5:2    262   END; (* L> 0 *)
 2453    1     5:1    262   RVAL := ISGN * (K + F);
 2454    1     5:0    279 END; (* RVAL *)
 2455    1     5:0    298
 2456    1     5:0    298
 2457    1     5:0    298 (*$P,IPROGS:CHARSUBS.TEXT*)
 2458    1     5:0    298         (***************************)
 2459    1     5:0    298
 2460    1     1:0      0 BEGIN (* MAIN PROGRAM *)
 2461    1     1:1      0   DEVICE := '';
 2462    1     1:1      9   ENDRUN := FALSE;
 2463    1     1:1     12   FIRSTRD := TRUE;
 2464    1     1:1     15   REPEAT
 2465    1     1:2     15     OPTIMIZE := FALSE;
 2466    1     1:2     18     MODIFY;
 2467    1     1:2     21     INDATA;
 2468    1     1:2     24     WRITELN('  EXISTING PLANT MODE');
 2469    1     1:2     61     VULCAN; (* RUN MODEL WITHOUT CONTROL *)
 2470    1     1:2     64     REPORT;
 2471    1     1:2     67
 2472    1     1:2     67     IF CPLEL > 0 (* RUN MODEL WITH CONTROL *)
 2473    1     1:2     71         THEN BEGIN
 2474    1     1:4     77           OPTIMIZE := TRUE;
 2475    1     1:4     80           WRITELN('  CONTROLLED OVEN OPTIMIZATION MODE');
 2476    1     1:4    131           VULCAN;
 2477    1     1:4    134           REPORT;
 2478    1     1:3    137         END;
 2479    1     1:2    137     WRITELN('DO YOU WISH TO RERUN PROGRAM? ');
 2480    1     1:2    183     IF NOT YES THEN ENDRUN := TRUE;
 2481    1     1:2    193     RUNNUM := RUNNUM + 0.01;
```

```
2482   1    1:1   209   UNTIL ENDRUN;
2483   1    1:1   213
2484   1    1:1   213   WRITELN;
2485   1    1:1   219   WRITELN('END OF OVEN ANALYSIS');
2486   1    1:0   255 END.
```

APPENDIX B

CHEMICAL COATERS ASSOCIATION DATA FORM

CHEMICAL COATERS ASSOCIATION

Data Form

Your cooperation in furnishing the information requested in behalf of the Chemical Coaters Association is greatly appreciated. This information will be utilized to analyze the operating cost, energy, and environmental benefits that are achievable by computer control of the oven air flows. Combined with information from other plants, the economics and design of the computer control system will be determined to assure widespread application throughout the industry.

If there are any questions in completing this data form, please contact Terry Karda or Roy Radanof of CENTEC Corporation (305/491-6660) or your Association Office.

PART A GENERAL DESCRIPTION

1. Corporate Name ______________________________

2. Address ______________________________

____

3. Form completed by *(Name, Title, and Telephone Number)*

____

4. Date ____________

5. Do you prefer confidentiality of the information that you have provided?

☐ Yes ☐ No

6. Would you want to be considered as host plant for prototype?
(A YES answer does not commit your plant at this time.)

☐ Yes ☐ No

7. Type of Products Coated:

☐ Construction Equipment ☐ Farm Implements ☐ Appliances ☐ Toys ☐ Auto/Truck Parts
☐ Other *(Indicate)* ____________

8. What type of coating operation is performed in your plant?

☐ Custom ☐ In-house

9. Potential plant-wide heat recovery applications: ____________

____

____

PART B COATING FORMULATION DESCRIPTION

1. Type(s) of Coatings:

☐ High Solids ☐ Water-Solvent ☐ Powder ☐ Enamel
☐ Lacquer ☐ Waterborne *(No solvent)* ☐ Other *(List)*

____

2. Type(s) of Coating Applications:

☐ Hot Melt ☐ Flow ☐ Electrodeposition ☐ Air Spray

☐ Dip ☐ Roller ☐ Electrostatic Spray ☐ Airless Spray

☐ Other *(Identify)* ______________________________

3. Approximate Number of Coating Formulations Handled: __________

4. List solvents contained in your major coating formulations *(Please indicate if the listed solvent is a brand name or a common chemical, where applicable.)*

____

____

____

5. Total Annual Organic Solvent Usage *(pounds/year or gallons/year)*

____

PART C CURING LINE DESCRIPTION *(Provide details for each oven.)*

(If plant location utilizes more than four curing ovens, please duplicate PART C to allow for complete information of all ovens.)

	1	2	3	4
1. Oven Size				
2. Oven Manufacturer				
3. Oven Type				
4. Annual Hours of Each Oven Operation				
5. Oven Air Flow Rate *(Nominal & Range)*				
6. Oven Air Flow Variability *(If variable, please provide details in PART D, #1.)*	☐ Fixed ☐ Variable	☐ Fixed ☐ Variable	☐ Fixed ☐ Variable	☐ Fixed ☐ Variable
7. Oven Inlet Air Temperature °F *(Nominal and Range)*				
8. Oven Exhaust Air Temperature °F *(Nominal and Range)*				

	1	2	3	4
9. Oven Fuel: a. Natural Gas b. #2 Fuel Oil c. Propane d. Other *(Identify)*	a. ☐ b. ☐ c. ☐ d. ☐	a. ☐ b. ☐ c. ☐ d. ☐	a. ☐ b. ☐ c. ☐ d. ☐	a. ☐ b. ☐ c. ☐ d. ☐
10. Annual Oven Fuel Consumption: a. Natural Gas b. #2 Fuel Oil c. Propane d. Other *(Identify)*	a. ☐ b. ☐ c. ☐ d. ☐	a. ☐ b. ☐ c. ☐ d. ☐	a. ☐ b. ☐ c. ☐ d. ☐	a. ☐ b. ☐ c. ☐ d. ☐
11. Is solvent Monitoring/control equipment employed? *(If YES, detail in PART D, #2.)*	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
12. Oven Solvent Concentration as % of LEL *(Nominal and Range)*				
13. Solvent Removal Rate *(Nominal and Range)*				
14. Type of Solvent Emmission Control Employed: a. Thermal Incineration b. Catalytic Incineration c. Carbon Adsorption d. None e. Other *(Identify)*	a. ☐ b. ☐ c. ☐ d. ☐ e. ☐	a. ☐ b. ☐ c. ☐ d. ☐ e. ☐	a. ☐ b. ☐ c. ☐ d. ☐ e. ☐	a. ☐ b. ☐ c. ☐ d. ☐ e. ☐

	1	2	3	4
15. Incinerator Inlet Air Temperature °F *(Nominal and Range)*				
16. Incinerator Control *(Exhaust)* Temperature °F *(Nominal and Range)*				
17. Minimum Reactivity Temperature at Catalyst Inlet °F				
18. Combustion Air Source for Incinerator: a. Outside Air *(External)* b. Waste Air from Oven *(Internal)* c. Other *(Identify)*	a. ☐ b. ☐ c. ☐	a. ☐ b. ☐ c. ☐	a. ☐ b. ☐ c. ☐	a. ☐ b. ☐ c. ☐
19. Incinerator Fuel: a. Natural Gas b. #2 Fuel Oil c. Propane d. Other *(Identify)*	a. ☐ b. ☐ c. ☐ d. ☐	a. ☐ b. ☐ c. ☐ d. ☐	a. ☐ b. ☐ c. ☐ d. ☐	a. ☐ b. ☐ c. ☐ d. ☐
20. Annual Incinerator Fuel Consumption: a. Natural Gas b. #2 Fuel Oil c. Propane d. Other *(Same as 19d)*	a. ______ b. ______ c. ______ d. ______	a. ______ b. ______ c. ______ d. ______	a. ______ b. ______ c. ______ d. ______	a. ______ b. ______ c. ______ d. ______

	1	2	3	4
21. Type of Heat Recovery Used				
a. Building Heat	a. ☐	a. ☐	a. ☐	a. ☐
b. Hot Water Heating	b. ☐	b. ☐	b. ☐	b. ☐
c. Preheat Incinerator Inlet Air from Oven	c. ☐	c. ☐	c. ☐	c. ☐
d. Preheat Oven Inlet Air	d. ☐	d. ☐	d. ☐	d. ☐
e. Preheat Incinerator Combustion Air	e. ☐	e. ☐	e. ☐	e. ☐
f. Preheat Oven Combustion Air	f. ☐	f. ☐	f. ☐	f. ☐
g. Waste Heat Boiler	g. ☐	g. ☐	g. ☐	g. ☐
h. Other *(Identify)*	h. ☐	h. ☐	h. ☐	h. ☐
22. Type of Heat Recovery Devices Used *(Select one or Combination)*				
a. Shell and Tube Exchanger	a. ☐	a. ☐	a. ☐	a. ☐
b. Rotating Wheel	b. ☐	b. ☐	b. ☐	b. ☐
c. Direct Air Mixing	c. ☐	c. ☐	c. ☐	c ☐
d. Heat Pipes	d. ☐	d. ☐	d. ☐	d. ☐
e. Stone Bed	e. ☐	e. ☐	e. ☐	e. ☐
f. Other *(Identify)*	f. ☐	f. ☐	f. ☐	f. ☐

PART D COMMENTS

1. Details on oven air flow variability ______

2. Details on solvent monitoring/control equipment and equipment manufacturers *(Specify which oven with details)*

3. Miscellaneous ______

4. Optional

(Please submit rough process flow schematics for each curing line.)

APPENDIX C

EXAMPLES OF PRINTOUTS FROM OVEN/INCINERATOR MODEL

```
                         OVEN-INCINERATOR DESIGN MODEL
                            (CONTROLLED OVEN MODE)

                        *** GENERAL INFORMATION ***

 PLANT NAME:                         DEMONSTRATION
 PROCESS DESCRIPTION:                MISC METAL PARTS
 PRODUCT DESCRIPTION:                OVEN AND THERMAL INC
 DATE:                               16 NOV 1981
 INPUT FILE NAME:
 RUN NUMBER:                                    1.00
 ANNUAL OPERATING HOURS:                      4000.0    HRS/YR
 SYSTEM GAS FLOW RATE:                       14898.0    LB/HR
                                              3250.0    SCFM
 COATING RATE:                                 200      LB/HR
 VOC DESTRUCTION EFF:                           98.0    %

                             * SOLVENT DATA *

 SOLVENT NAME                MIXTURE   OVEN REMOVAL RATE    AUX REMOVAL RATE
                               (%)         (LBS/HR)              (LBS/HR)
 SOLVESSO-150                 90.00        180.00                  0.00
 TOLUENE                      10.00         20.00                  0.00

                              * FUEL COSTS *

   NATURAL GAS                                 3.80    $/(MM BTU)
   OIL                                         6.30    $/(MM BTU)
   PROPANE                                     4.50    $/(MM BTU)


                            *** CURING OVEN ***

 OVEN TYPE:                          CONVEYOR
 FUEL:                               NG
 OVEN GAS FLOW RATE:                      14898.0    LB/HR
                                           3250.0    SCFM
 COMBUSTION AIR SOURCE:              INTERNAL
 INLET AIR TEMPERATURE,TO:                  70       DEG-F
 EXHAUST AIR TEMPERATURE,T1:               256       DEG-F
 PREHEAT AIR TEMPERATURE,TP:                70       DEG-F
 EXCESS COMBUSTION AIR:                     20.00    %
 GASES RECYCLED:                             0.00    %
 SPECIFIC HEAT OF PRODUCT:                   0.50    BTU/LB DEG-F
 PRODUCT MASS FLOW RATE:                  1000.00    LB/HR
 OVEN SURFACE AREA:                       8000.00    SQ-FT
 RADIATION HEAT TRANSFER COEFFICIENT:        0.80    BTU/(SQ-FT DEG-F HR)
 PERCENT OF LEL:                            26.21    %
 RADIATION HEAT LOSS:                        1.1904 (MM BTU)/HR
 FUEL MASS FLOW RATE:                       96.89    LB/HR
                                             2.3136 (MM BTU)/HR
                                          2283.19    SCF/HR
 ANNUAL COST:                            35167.0     $/YR
```

```
                              *** AFTERBURNER ***

AFTERBURNER TYPE:                          THERMAL
FUEL TYPE:                                 NG
COMBUSTION AIR SOURCE:                     INTERNAL
INLET TEMPERATURE,T2:                             256        DEG-F
EXHAUST TEMPERATURE,T3:                          1450        DEG-F
EXCESS COMBUSTION AIR                              20.00     %
SURFACE AREA                                     1000.00     SQ-FT
RADIATION HEAT TRANSFER COEFFICIENT:                0.90     BTU/(SQ-FT DEG-F HR)
MAXIMUM INLET TEMPERATURE:                        900.76     DEG-F
FUEL MASS FLOW RATE:                              129.38     LB/HR
                                                    3.0895   (MM BTU)/HR
                                                 3048.89     SCF/HR
RADIATION HEAT LOSS:                                1.2420   (MM BTU)/HR
ANNUAL COST:                                    46961.0      $/YR
```

```
                    OVEN-INCINERATOR DESIGN MODEL
                       (EXISTING PLANT MODE)

                     *** GENERAL INFORMATION ***

PLANT NAME:
PROCESS DESCRIPTION:                   DEMONSTRATION
PRODUCT DESCRIPTION:                   MISC METAL PARTS
DATE:                                  OVEN AND THERMAL INC
INPUT FILE NAME:                       16 NOV 1981
RUN NUMBER:
ANNUAL OPERATING HOURS:                           1.00
SYSTEM GAS FLOW RATE:                          4000.0    HRS/YR
                                              44373.1    LB/HR
COATING RATE:                                  9680.0    SCFM
VOC DESTRUCTION EFF:                            200      LB/HR
                                                 98.0    %

                          * SOLVENT DATA *

SOLVENT NAME
                          MIXTURE   OVEN REMOVAL RATE    AUX REMOVAL RATE
SOLVESSO-150                (%)        (LBS/HR)             (LBS/HR)
TOLUENE                    90.00        180.00                 0.00
                           10.00         20.00                 0.00

                           * FUEL COSTS *

 NATURAL GAS
 OIL                                             3.80    $/(MM BTU)
 PROPANE                                         6.30    $/(MM BTU)
                                                 4.50    $/(MM BTU)

                        *** CURING OVEN ***

OVEN TYPE:
FUEL:                                 CONVEYOR
OVEN GAS FLOW RATE:                   NG
                                              44373.1    LB/HR
COMBUSTION AIR SOURCE:                         9680.0    SCFM
INLET AIR TEMPERATURE,T0:             INTERNAL
EXHAUST AIR TEMPERATURE,T1:                    70        DEG-F
PREHEAT AIR TEMPERATURE,TP:                   256        DEG-F
EXCESS COMBUSTION AIR:                         70        DEG-F
GASES RECYCLED:                                20.00     %
SPECIFIC HEAT OF PRODUCT:                       0.00     %
PRODUCT MASS FLOW RATE:                         0.50     BTU/LB DEG-F
OVEN SURFACE AREA:                           1000.00     LB/HR
RADIATION HEAT TRANSFER COEFFICIENT:         8000.00     SQ-FT
PERCENT OF LEL:                                 0.80     BTU/(SQ-FT DEG-F HR)
RADIATION HEAT LOSS:                            8.80     %
FUEL MASS FLOW RATE:                            1.1904   (MM BTU)/HR
                                              161.23     LB/HR
                                                3.8501   (MM BTU)/HR
ANNUAL COST:                                 3799.46     SCF/HR
                                            58521.0      $/YR
```

```
                               *** AFTERBURNER ***
AFTERBURNER TYPE:                      THERMAL
FUEL TYPE:                             NG
COMBUSTION AIR SOURCE:                 INTERNAL
INLET TEMPERATURE,T2:                            256      DEG-F
EXHAUST TEMPERATURE,T3:                         1450      DEG-F
EXCESS COMBUSTION AIR                             20.00   %
SURFACE AREA                                    1000.00   SQ-FT
RADIATION HEAT TRANSFER COEFFICIENT:               0.90   BTU/(SQ-FT DEG-F HR)
MAXIMUM INLET TEMPERATURE:                      1253.45   DEG-F
FUEL MASS FLOW RATE:                             556.99   LB/HR
                                                  13.3005 (MM BTU)/HR
                                               13125.6    SCF/HR
RADIATION HEAT LOSS:                               1.2420 (MM BTU)/HR
ANNUAL COST:                                  202167.     $/YR
```

APPENDIX D

MICROCOMPUTER LEL CONTROL SYSTEM

HAZARD/RISK ANALYSIS

August, 1980

Scope

A process hazard/risk analysis should include an intensive and systematic examination of the designated process for exposures to personnel and property. This examination must consider both the theoretical and practical review standpoint.

The purpose of this risk analysis is to compare the safety of the microcomputer controlled oven operating at solvent concentration approaching 50 percent of the LEL and a standard oven, not utilizing this LEL control technology.

The two methods of risk investigation used are the "What If" and the "Fault Tree Analysis" methods. The "What If" method, which is the most common, is based on the formulation of what if questions and answers in order to evaluate the effects of component failure or procedural errors on the process. This deals primarily with the microcomputer controller design, and not the system comparison. The "Fault Tree Analysis" method will compare the controlled oven and the standard oven assessing the effects of component failures based on the occurence of these component failures.

"What If" Method

The following questions were formulated and the answers generated based on the curing system retrofit with the microcomputer control system.

"What If" Method

QUESTION: What if....?	ANSWER
the LEL analyzer sample line plugs	- Low flow switch would signal microcomputer to fully open damper and signal operator
the calibration gas pressure goes to zero	- Low pressure switch would signal microcomputer to fully open damper and signal operator
the analyzer fuel pressure goes to zero	- Low pressure switch would signal microcomputer to fully open damper and signal operator
the LEL level exceeds limit set point	- High level alarm would be actuated and the microcomputer signaled to fully open damper; if level continues to increase conveyor and coating application would be terminated
the process instrument air pressure goes to zero	- low pressure switch would signal microcomputer and damper would fail fully open.
the VOC destruction efficiency falls below set level	- temperature control on incinerator must be increased manually
an electrical power outage	- dampers would fail fully open, conveyor would stop, and the oven and incinerator fuel valve would be closed
a coating and/or product line changeover	- analyzer would sense increase in LEL and would signal microcomputer to open dampers; an error of 10 percent maximum can occur with solvent variation, but this would be be accounted for by a 40 percent LEL limit set point, i.e 44 percent LEL maximum with error.

the sample line electrical tracing fails	-	Sample could condense in line and cause a pluggage which would activate low flow switch, signal micro-computer and fully open dampers.
the primary heat recovery unit plugs	-	out of range pressure and temperature readings would be sensed by the micro-computer to shutdown system manually unless high LEL is realized.
the exhaust blower fails	-	out of range pressure reading would be sensed by the microcomputer if high LEL then dampers fully open, if LEL set point limit exceeded then system shut down.

Based on the "What If" method of analysis (see Table 1), the micro-computer control system as designed would safely handle all of the potential hazardous conditions and equipment failures.

"Fault Tree Analysis" Method

This method is a systematic technique for helping to insure a safer system design and operation. Its use has been primarily limited to the aerospace industry; only recently has it begun to have application in the general chemical industry.

A fault tree is a schematic of the primary potentially hazardous initial, intervening, and final events which could result in an undesired event, such as a flame propagating explosion. The objective of the analysis is to determine how the processing system, including the personnel involved, could fail and cause the undesired event.

A fault tree is constructed using logic symbol (Figure 1) to properly relate all possible sequences of events that could result in the undesired event.

The possible causes of this event, termed subevents, are displayed in the form of a tree in decending order of their occurence. The fault tree for the oven explosion event shown in Figure 2 are subevent details for the LEL analyzer signal failure, pressure control problem, closed damper, and the fan failure. The failure sequences can be identified from the fault tree by utilizing the subevent number or letter designations and the logic probability arithmetic. From these failure sequences, the "critical path" is determined by visual inspection of the fault tree.

The critical failure paths were developed for the controlled oven (see Table 2) and the standard oven (see Table 3). The component "Failure Rates" are then incorporated into the critical path and the probability of the undesired event occuring is determined. The letters shown in each table are keyed to subevents in Figure 2. These failure rates were estimated based on component operation in the chemical industry shown in Table 4.

The standard oven probability of explosion is one incident in 7.4 days. This is much higher than would be expected, because the failure rates utilized were based on a chemical plant which has more severe operational and evironmental conditions than a curing plant.

The controlled oven probability of explosion utilizing microcomputer technology is one incident in 672 years. The comparison of the controlled oven and the standard oven probabilities of explosion exhibits that the controlled oven will be extremely safer to operate.

Table 1 "WHAT IF" ANALYSIS

	PROBLEM	DETECTION METHOD	ACTION REQUIRED
	WHAT IF.............		
1.	#1 LEL analyzer sample line plugs?	Low sample flow activates low flow switch.	Microcomputer signals oven exhaust damper to full open and activates alarm.
2.	#2 LEL analyzer sample line plugs?	Low sample flow activates low flow switch.	Microcomputer signals oven exhaust damper to full open and activates alarm.
3.	#1 LEL analyzer low flow switch fails to indicate low flow?	#1 LEL analyzer output will differ from #2 LEL analyzer output when compared by the microcomputer.	Microcomputer signals oven exhaust damper to full open and activates alarm.
4.	#2 LEL analyzer low flow switch fails to indicate low flow?	#2 LEL analyzer output will differ from #1 LEL analyzer output when compared by the microcomputer.	Microcomputer signals oven exhaust damper to full open and activates alarm.
5.	#1 LEL analyzer calibration gas pressure is low?	#1 LEL analyzer low pressure switch is activated.	Microcomputer signals oven exhaust damper to full open and activates alarm.
6.	#2 LEL analyzer calibration gas pressure is low?	#2 LEL analyzer low pressure switch is activated.	Microcomputer signals oven exhaust damper to full open and activates alarm.
7.	#1 LEL analyzer calibration gas low pressure switch fails to operate?	Microcomputer "knows" what value the analyzer should be reading when the analyzer is in the calibration mode and will compare the output of the analyzer to the value in the microcomputer's memory.	Microcomputer signals oven exhaust damper to full open and activates alarm.

Table 1 "WHAT IF" ANALYSIS
(Continued)

	PROBLEM	DETECTION METHOD	ACTION REQUIRED
8.	#2 LEL analyzer calibration gas low pressure switch fails to operate?	Microcomputer "knows" what value the analyzer should be reading when the analyzer is in the calibration mode and will compare the output of the analyzer to the value in the microcomputer's memory.	Microcomputer signals oven exhaust damper to full open and activates alarm.
9.	#1 LEL analyzer sample line electrical heat tracing fails?	Quantity of sample may be reduced due to condensing of the VOC component which will cause the #1 LEL analyzer output to differ from the output of the #2 LEL analyzer when compared by the microcomputer.	Microcomputer signals oven exhaust damper to full open and activates alarm.
10.	#2 LEL analyzer sample line electrical heat tracing fails?	Quantity of sample may be reduced due to condensing of the VOC component which will cause the #2 LEL analyzer output to differ from the output of the #1 LEL analyzer when compared by the microcomputer.	Microcomputer signals oven exhaust damper to full open and activates alarm.
11.	The LEL level exceeds the limit set point on either analyzer?	Analyzer output would be higher than set point.	Analyzer activates high LEL level alarm, and microcomputer signals oven exhaust damper to full open. If level continues to increase, then the product conveyor and coating appliction would be stopped.
12.	The process instrument air pressure is low?	Low instrument air pressure activates a low pressure switch.	Damper activators have built-in safety feature which causes them to fail open on low instrument air pressure.

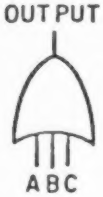
Table 1 "WHAT IF" ANALYSIS
(Continued)

PROBLEM	DETECTION METHOD	ACTION REQUIRED
13. The process instrument air pressure drops below normal and the low pressure switch fails to operate?	Limit switches on dampers will indicate a change in positioning.	All dampers in oven system will fail open causing limit switches to indicate fully open dampers.
14. A power outage occurs?	Total system is down.	All dampers would fail open, the product conveyor would stop and the oven and incinerator fuel valves would fail closed.
15. The oven exhaust damper fails to go full open for items 1 through 10 above?	Limit switch on damper assembly is not activated within a predetermined time interval which activates an alarm.	Operator must manually open damper to full open. If the solvent concentration should exceed the analyzers' set point before the damper is fully opened, then the microcomputer will stop the product conveyor and the coating application.
16. The oven fuel control valve fails to close on demand?	Limit switches doe not indicate a closed valve and oven temperature would increase.	High temperature cut-off will activate existing safety valve in oven fuel system (as per NFPA 86 A).
17. The VOC destruction efficiency falls below the desired level?	Microcomputer computes destruction efficiency based on solvent concentration detected by analyzers at the exit of the oven and at the exit of the incinerator and compares the computed value to the desired level.	Temperature control on incinerator would be manually adjusted.
18. A coating and/or product line changeover occurs?	LEL analyzers would sense a change in the measured solvent concentration.	Microcomputer would adjust dampers to bring solvent concentration back to set point.

Table 1 "WHAT IF" ANALYSIS
(Continued)

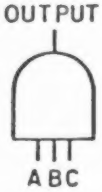
	PROBLEM	DETECTION METHOD	ACTION REQUIRED
19.	The primary heat recovery unit begins to plug?	Differential pressure and temperature sensors located in the inlet and outlet ducting will indicate values out of the normal operating range as monitored by the microcomputer.	Microcomputer will activate alarm to manually shut the system down. If a high LEL is detected by the analyzers before the operator manually shuts the system down, the analyzers will automatically deactivate the product conveyor and close the fuel valve.
20.	A temperature or pressure sensor in the primary heat recovery inlet and/or outlet ducting malfunctions?	Microcomputer monitor system will detect malfunctioning unit. Since a sensor is located in each of the inlet/outlet ducts, a certain degree of redundancy is provided to double check monitoring integrity.	Microcomputer will activate alarm of a malfunctioning unit.
21.	The exhaust blower fails?	Existing NFPA 86A requirements specify that an electrical interlock be provided between the exhaust blower and the oven fuel. Also, an out of range pressure reading and a high LEL in the oven would be sensed by the microcomputer.	The electrical interlock will shut-off the fuel valve and the conveyor system. If the interlock should fail, the microcomputer and analyzer system will act as back-up to shuting off the conveyor and closing the fuel valve.
22.	An operator over charges solvent to oven?	LEL analyzer will detect increasing solvent concentration.	As solvent increases, dampers will be opened. If LEL set point is exceeded then microcomputer will completely shut system down and alarm.

SYMBOLS



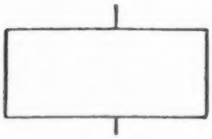
"OR" Gate

This gate is in the failed state if at least one of its inputs is in the failed state.
Probability of Output = Probability of A + B + C



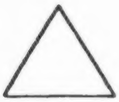
"AND" Gate

This gate is in the failed state only if all its inputs are simultaneously in their failed states.
Probability of Output = Probability of A x B x C



Subevent

The rectangle describes the event which is the output of a logic gate.



Transfer

The triangle transfers an entire part of the tree to another location on the tree or to another page of a subdivided tree.

Figure 1 Symbols For Fault Tree Analysis

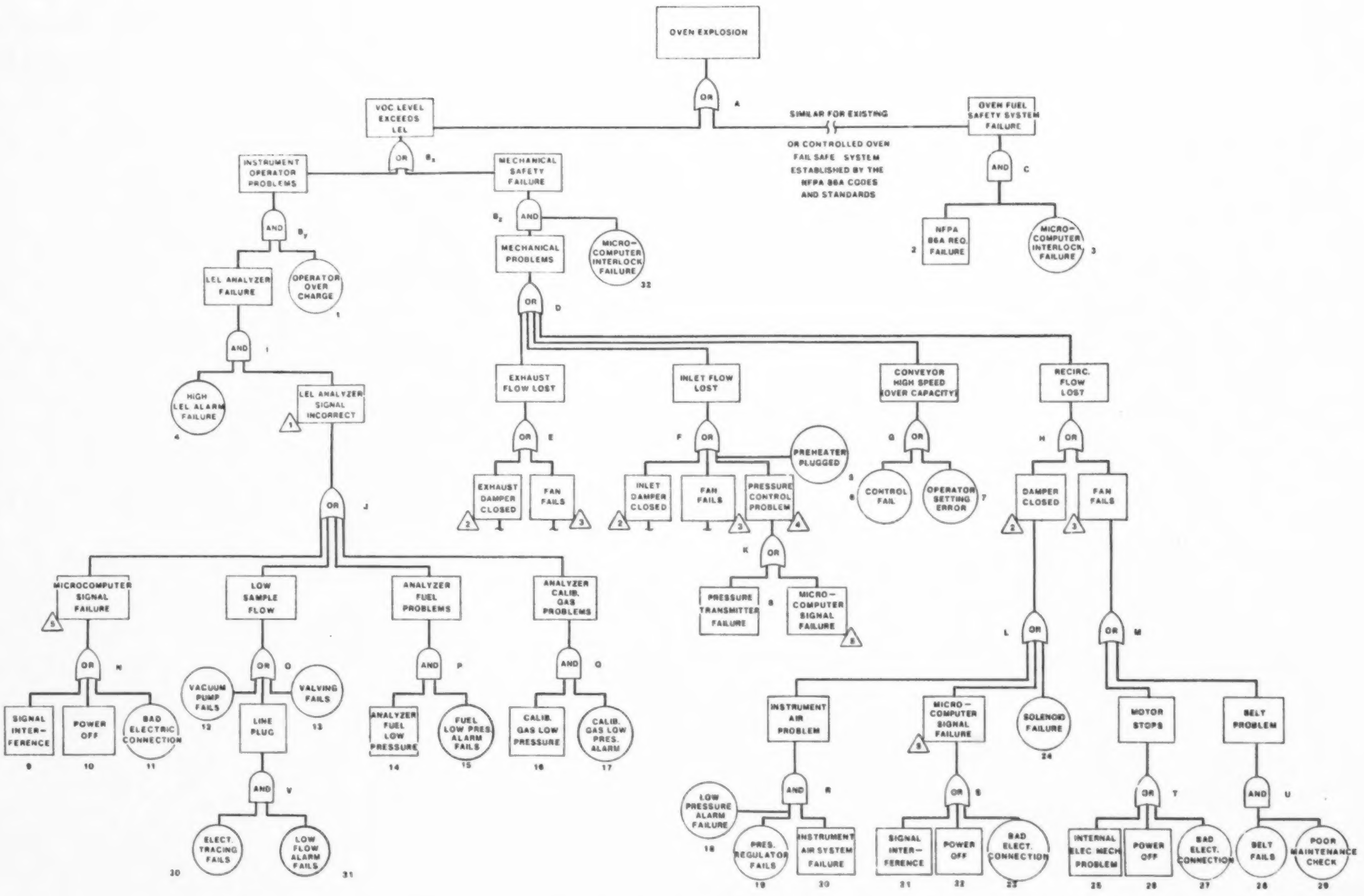

OVEN EXPLOSION
OR
A
VOC LEVEL EXCEEDS LEL
SIMILAR FOR EXISTING
OR CONTROLLED OVEN FAIL SAFE SYSTEM ESTABLISHED BY THE NFPA 86A CODES AND STANDARDS
OVEN FUEL SAFETY SYSTEM FAILURE
AND
C
NFPA 86A REQ. FAILURE
2
MICRO-COMPUTER INTERLOCK FAILURE
3
OR
B_x
INSTRUMENT OPERATOR PROBLEMS
MECHANICAL SAFETY FAILURE
AND
B_y
LEL ANALYZER FAILURE
OPERATOR OVER CHARGE
1
AND
I
HIGH LEL ALARM FAILURE
4
LEL ANALYZER SIGNAL INCORRECT
1
OR
J
MICROCOMPUTER SIGNAL FAILURE
5
OR
N
SIGNAL INTER-FERENCE
9
POWER OFF
10
BAD ELECTRIC CONNECTION
11
LOW SAMPLE FLOW
OR
O
VACUUM PUMP FAILS
12
VALVING FAILS
13
LINE PLUG
AND
V
ELECT. TRACING FAILS
30
LOW FLOW ALARM FAILS
31
ANALYZER FUEL PROBLEMS
AND
P
ANALYZER FUEL LOW PRESSURE
14
FUEL LOW PRES. ALARM FAILS
15
ANALYZER CALIB. GAS PROBLEMS
AND
Q
CALIB. GAS LOW PRESSURE
16
CALIB. GAS LOW PRES. ALARM
17
B_z
AND
MECHANICAL PROBLEMS
MICRO-COMPUTER INTERLOCK FAILURE
32
OR
D
EXHAUST FLOW LOST
OR
E
EXHAUST DAMPER CLOSED
2
FAN FAILS
3
INLET FLOW LOST
F
OR
INLET DAMPER CLOSED
2
FAN FAILS
3
PRESSURE CONTROL PROBLEM
4
PREHEATER PLUGGED
5
K
OR
PRESSURE TRANSMITTER FAILURE
8
MICRO-COMPUTER SIGNAL FAILURE
5
CONVEYOR HIGH SPEED (OVER CAPACITY)
G
OR
CONTROL FAIL
6
OPERATOR SETTING ERROR
7
RECIRC. FLOW LOST
H
OR
DAMPER CLOSED
2
FAN FAILS
3
L
OR
INSTRUMENT AIR PROBLEM
AND
R
LOW PRESSURE ALARM FAILURE
18
PRES. REGULATOR FAILS
19
INSTRUMENT AIR SYSTEM FAILURE
20
MICRO-COMPUTER SIGNAL FAILURE
5
OR
S
SIGNAL INTER-FERENCE
21
POWER OFF
22
BAD ELECT. CONNECTION
23
SOLENOID FAILURE
24
OR
M
MOTOR STOPS
OR
T
INTERNAL ELEC MECH PROBLEM
25
POWER OFF
26
BAD ELECT. CONNECTION
27
BELT PROBLEM
AND
U
BELT FAILS
28
POOR MAINTENANCE CHECK
29

Figure 2. Fault Tree--Microcomputer Controlled/Existing Curing Ovens

Table 2

Subevent Probabilities - Controlled Oven (failures/hour)

1. $V = 30 \times 31 = (1 \times 10^{-5}) (1 \times 10^{-4}) = 1 \times 10^{-9}$
2. $N = 9 + 10 + 11 = S = (1.9 \times 10^{-4}) + (1.1 \times 10^{-4}) + (7.1 \times 10^{-6}) = 3.071 \times 10^{-4}$
3. $O = 12 + V + 13 = (7.6 \times 10^{-5}) + (1 \times 10^{-9}) + (1 \times 10^{-6}) = 7.7 \times 10^{-5}$
4. $P = 14 \times 15 = (1.4 \times 10^{-3}) (1 \times 10^{-4}) = 1.4 \times 10^{-7}$
5. $Q = 16 \times 17 = (1.4 \times 10^{-3}) (1 \times 10^{-4}) = 1.4 \times 10^{-7}$
6. $R = 18 \times 19 \times 20 = (1 \times 10^{-4}) (2.16 \times 10^{-6}) (1 \times 10^{-4}) = 2.2 \times 10^{-14}$
7. $S = 21 + 22 + 23 = N = 3.071 \times 10^{-4}$
8. $T = 25 + 26 + 27 = (1 \times 10^{-5}) + (1.1 \times 10^{-4}) + (7.1 \times 10^{-6}) = (1.17 \times 10^{-4})$
9. $U = 28 \times 29 = (4 \times 10^{-5}) (4.2 \times 10^{-3}) = 16.8 \times 10^{-8}$
10. $J = N + O + P + Q = (3.071 \times 10^{-4}) + (7.7 \times 10^{-5}) + (1.4 \times 10^{-7}) + (1.4 \times 10^{-7}) = 3.84 \times 10^{-4}$
11. $K = 8 + N = (4.4 \times 10^{-5}) + (3.071 \times 10^{-4}) = (3.51 \times 10^{-4})$
12. $L = R + S + 24 = (2.2 \times 10^{-14}) + (3.071 \times 10^{-4}) + (4 \times 10^{-7}) = 3.075 \times 10^{-4}$
13. $M = T + U = (1.17 \times 10^{-4})) + (1.68 \times 10^{-7}) = (1.17 \times 10^{-4})$
14. $I = J \times 4 = (3.84 \times 10^{-4}) (1 \times 10^{-4}) = 3.84 \times 10^{-8}$
15. $E = L + M = H = (3.075 \times 10^{-4}) + (1.17 \times 10^{-4}) = 4.245 \times 10^{-4}$
16. $F = E + K + 5 = (4.245 \times 10^{-4}) + (3.51 \times 10^{-4}) + (1.1 \times 10^{-5}) = 7.865 \times 10^{-4}$
17. $G = 6 + 7 = (2.4 \times 10^{-4}) + (1.25 \times 10^{-4}) = 3.65 \times 10^{-4}$
18. $D = E + F + G + H = (8.49 \times 10^{-4}) + (7.865 \times 10^{-4}) + (3.65 \times 10^{-4}) = 2.0 \times 10^{-3}$
19. $B_y = I \times 1 = (3.84 \times 10^{-8}) (4.2 \times 10^{-3}) = 1.61 \times 10^{-10}$
20. $B_z = D \times 32 = (2.0 \times 10^{-3}) (7.6 \times 10^{-5}) = 1.52 \times 10^{-7}$
21. $B_x = B_y + B_z = (1.52 \times 10^{-7}) + (1.61 \times 10^{-10}) = (1.52 \times 10^{-7})$
22. $C = 2 \times 3 + (2.4 \times 10^{-4}) (7.6 \times 10^{-5}) = 1.82 \times 10^{-8}$
23. $A = B_x + C = (1.52 \times 10^{-7}) + (1.82 \times 10^{-8}) = 1.70 \times 10^{-7}$*

*NOTE: Controlled oven probability of explosion is one incident in 672 years.

Table -3

Subvent Probabilities - Standard Oven
(failures/hour)

1. $U = 28 \times 29 = 1.68 \times 10^{-7}$
2. $T = 25 + 26 + 27 = 1.17 \times 10^{-4}$
3. $M = T + U = (1.17 \times 10^{-4}) + (1.68 \times 10^{-7}) = 1.17 \times 10^{-4}$
4. $L = (3 \times 10^{-5}) + (1.25 \times 10^{-4}) = 1.55 \times 10^{-4}$
5. $G = 6 + 7 = 3.65 \times 10^{-4}$
6. $F = L + M = 5 = (1.55 \times 10^{-4}) + (1.17 \times 10^{-4}) + (1.1 \times 10^{-5}) = 2.83 \times 10^{-4}$
7. $E = H = L + M = 2.72 \times 10^{-4}$
8. $D = B_z = E + F + G + H = (5.44 \times 10^{-4}) + (3.65 \times 10^{-4}) + (2.83 \times 10^{-4}) = 1.19 \times 10^{-3}$
9. $B_y = 1 = 4.2 \times 10^{-3}$
10. $B_x = B_y + B_z = (4.2 \times 10^{-3}) + (1.19 \times 10^{-3}) = 5.39 \times 10^{-3}$
11. $C = 2 = 2.4 \times 10^{-4}$
12. $A = B_x + C = (2.4 \times 10^{-4}) + (5.39 \times 10^{-3}) = 5.63 \times 10^{-3}$*

*NOTE: Standard oven probability of undesirable event is one indicent in 7.4 days.

Table 4
Failure Rates

Component	Average (Failures/hr or/day)
Plant Air	1 X 10^{-4}
Pneumatic Connections	1.5 X 10^{-6}
Air Tube Rupture	2.5 X 10^{-5}
Air Tube Plug	1.4 X 10^{-5}
LEL Analyzer	2 X 10^{-4}
Blowers, Fans	2.4 X 10^{-6}
Alarm Horns	6 X 10^{-7}
Pneumatic/Electric Controllers	4.3 X10^{-4}
P Transmitters (pressure)	4.4 X 10^{-5}
Ducts Rupture	1 x 10^{-10}
Leak	5.12 X 10^{7}
Computer (Electronics)	7.1 X 10^{-6}
P Transmitters (Flow)	2.1 X 10^{-4}
Gauges (Pres. & Temp)	1 X 10^{-5}
Heat Exchangers (Plug/Rupture)	1.5 x 10^{-5}
I/P Convertors	6.2 X 10^{-5}
Switches (P&T)	1 X 10^{-4}
Solenoids	4 X 10^{-7}
Instrumentation	
mV/I Transducer	1.9 X 10^{-4}
Control Loops	2.4 X 10^{-4}
Trip Interlock	7.6 X 10^{-5}
Alarm Lights	5 X 10^{-6}
Motors	
Starters	1.6 X 10^{-6}
Elect. Fail to Start	3 X 10^{-4}/day
Elect. Fail to Run	1 X 10^{-5}
Piping	
Rupture	1 X 10^{-9}
Joint Leak	1 X 10^{-6}
Power Failure (On/Off)	1.1 X 10^{-4}
Power Supply	3.5 X 10^{-5}

Table 4

Failure Rates Continued

Component	Average (Failures/hr or/day)
Purge Systems	1.2×10^{-4}
Recorders	2.5×10^{-5}
Regulators (Flow and Pressure)	2.14×10^{-6}
Flame Failure Detectors	1.6×10^{-4}
Temp. Transmitter	2.5×10^{-5}
Valves/Dampers	
Control-Electric	1×10^{-6}
Control-Pneumatic (Positiones)	3×10^{-5}
Human Failure Rates:	
Operator Equipment Setting Error	1.25×10^{-4}
Poor Maintenance Check	4.2×10^{-3}
Operator Conveyor Loading Error	4.2×10^{-3}

References

1. Green and Bourne, "Reliability Technology" pp. 563-570, Wiley (1972).

2. Anyakora, S.N. et al, "Some Data on the Reliability of Instruments in the Chemical Plant Environment," Chemical Engineer No. 255, pp. 396-402 (Nov.1971).

   Also see: Lees, F.P., "Some Data on the Failure Modes of Instruments in the Chemical Plant Environment," Chemical Engineer No. 277, pp. 418-421 (Sept. 1973).

3. Deuschle, R.S., and Goldberg, J., "A Reliability Primer, Parts 1 and 2," Instruments and Control Systems, 47 (2), 51 and 47 (3), 67 (Feb. and Mar. 1974).

4. "Reliability of Electrical Equipment," Institute of Electrical and Electronics Engineers Transaction on Industry Applications, Vol. 1A-10, No. 2, (Mar./Apr. 1974).

5. Ganick, B.J., et al, HN-190, USAEC Research and Development Report, May 1967.

APPENDIX E

SPECIFICATIONS FOR DAMPERS AND ACTUATORS

REVISIONS			
SPEC NO.	DATE	BY	CHKD.
243-6	5/13/81	TJK	

CHARGE NO.		AREA
ITEM NO.	PCV-1,2	
	BY	DATE
MADE		
CHKD.		
APPROV.		

NAME: COLOR & PRIME OVEN EXHAUST FLOW CONTROL DAMPERS

NO. REQD.: 2

FUNCTION:

TWO (2) PRESSURE INDEPENDENT, AUTOMATED DAMPERS ASSEMBLIES WITH FLOW SENSORS, PNEUMATICALLY CONTROLLED, FOR CONSTANT, OVEN EXHAUST, FLOW CONTROL AT THE FOLLOWING CONDITIONS:

A. COLOR & PRIME OVEN EXHAUST CONTAINING ORGANIC SOLVENTS

AIR FLOW RATE - 0 TO 2000 SCFM
TEMPERATURE - 220°F (UP TO 250°F MAX.)
DUCTSIZE - 18" x 20"
OPERATING PRESSURE - -3.5" W.C. TO -3.8" W.C.

NOTE: DAMPER TO FAIL OPEN

VENDOR TO PROVIDE WITH QUOTATION:
1. INSTALLATION REQUIREMENTS AND INSTRUCTION DETAILS
2. APPROVAL DRAWINGS FOR REVIEW
3. PARTS LIST

RECOMMENDED VENDOR:

1. METAL IND., INC.
PO BOX 4490
CLEARWATER, FLORIDA
33518
ATT: MR. LES MILEWSKI

METAL AIRE SERIES 212-TH OR EQUIVALENT WITH OUTLET COLLAR

REVISIONS			
SPEC NO.	DATE	BY	CHKD.
243-7	5/14/81	TJK	

CHARGE NO.		AREA
ITEM NO. FCV-1,2		
	BY	DATE
MADE		
CHKD.		
APPROV.		

NAME: DIP OVEN MAKE-UP AIR INLET DAMPERS NO. REQD. TWO (2)

FUNCTION:

TWO (2) PNEUMATICALLY ACTUATED DAMPERS (LOUVER OR SLIDE GATE) INCLUDING PNEUMATIC ACTUATOR, ACTUATOR POSITIONER, AND ADJUSTABLE MECHANICAL STOPS FOR THE CONTROL OF MAKE-UP AIR FLOW INTO THE TWO DIP OVEN ZONES.

A. ACTUATOR INPUT	3 PSIG	- OPEN FULL 100%
	15 PSIG	- CLOSED FULLY
B. MAKE-UP AIR RATES	0 - 1,000 SCFM AMBIENT AIR	
C. OPERATING TEMPERATURES	80 - 250°F	(DAMPER CONTROLS @ 100°F MAX.)
D. DUCT SIZE	EXIST OVEN OPENING	10" x 16" RECT.
	EXIST FILTER HOUSING	20" x 40" RECT.

NOTE: THE SIGNAL TO THE DAMPER ACTUATOR WILL BE PROVIDED BY A MICROCOMPUTER CONTROLLER SIGNAL OF 4 - 20 mA TO AN I/P CONVERTOR RESULTING IN THE 3 - 15 psi SIGNAL.
IF VENDOR CAN PROVIDE I/P CONVERTOR(S) AS PART OF DAMPER(S), PLEASE QUOTE WITH AND WITHOUT I/P CONVERTOR.

RECOMMENDED VENDORS:

1. METALIND INC.
PO BOX 4490
CLEARWATER, Fla
(813) 441-2651
ATT: MR. LEN MILEWSKI

2. HONEYWELL SERVICELINE
SALES OFFICE
PHILADELPHIA, PA
(215) 666-8200

SPEC. REVISIONS			
NO.	DATE	BY	CHKD.
243-8	5/16/81	TJE	

CHARGE NO.		AREA
ITEM NO. FCV-3		
	BY	DATE
MADE		
CHKD.		
APPROV.		

NAME: DIP OVEN EXHAUST AIR DAMPER NO. REQD. ONE (1)

FUNCTION·

ONE (1) PNEUMATICALLY ACTUATED DAMPER (LOUVER STYLE OPPOSED BLADES) INCLUDING PNEUMATIC ACTUATOR, ACTUATOR POSITIONER, AND ADJUSTABLE MECHANICAL STOPS FOR THE CONTROL OF OVEN EXHAUST AIR FLOW.

A. ACTUATOR INPUT	3 PSIG - OPEN 50% 15 PSIG - CLOSED FULLY
B. EXHAUST AIR RATES	400 - 3,400 SCFM (CONTAINING ORGANIC SOLVENTS)
C. OPERATING TEMPERATURE	220-250°F (DAMPER CONTROLS @ 100°F MAX)
D. DUCT SIZE	18" x 20" RECTANGULAR

NOTE: THE SIGNAL TO THE DAMPER ACTUATOR WILL BE PROVIDED BY A MICROCOMPUTER CONTROLLER SIGNAL OF 4-20 mA. TO AN I/P CONVERTOR RESULTING IN THE 3-15 psig SIGNAL.
IF VENDOR CAN PROVIDE I/P CONVERTOR AS PART OF DAMPER, PLEASE QUOTE WITH AND WITHOUT I/P CONVERTOR.

RECOMMENDED VENDORS:

1. METAL IND, INC
PO BOX 4490
CLEARWATER, FLA.
(813) 441-2651
ATT: LEW MILEWSKI

2. HONEYWELL SERVICELINE
SALES OFFICE
PHILADELPHIA, PA.
(215) 666-8200

REVISIONS			
NO.	DATE	BY	CHKD.
243-9	6/21/81	TJK	

CHARGE NO.	AREA
ITEM NO.	

	BY	DATE
MADE		
CHKD.		
APPROV.		

NAME: FUME TUNNEL EXHAUST FLOW CONTROL DAMPER NO. REQD. ONE (1)

FUNCTION·

ONE(1) PRESSURE INDEPENDENT, AUTOMATED DAMPER ASSEMBLY WITH FLOW SENSOR, PNEUMATICALLY CONTROLLED FOR CONSTANT AIR EXHAUST FLOW CONTROL AT THE FOLLOWING CONDITIONS:

AIR FLOW RATE - 0 TO 1840 SCFM CONTAINING ORGANIC SOLVENTS
TEMPERATURE - 85°F
DUCT SIZE - 15" ROUND
OPERATING PRESSURES - 2.0" W.C. TO -3.8" W.C.

NOTE: DAMPER TO FAIL OPEN

VENDOR TO PROVIDE WITH QUOTATION:

1. INSTALLATION REQUIREMENTS AND INSTRUCTION DETAILS
2. APPROVAL DRAWINGS FOR REVIEW
3. PARTS LIST

RECOMMENDED VENDOR:

1. METAL IND, INC.
PO BOX 4490
CLEARWATER, FLA.
33518

ATT: MR. LES MILEWSKI

METAL-AIRE SERIES "RETRO II" SIZE 1A OR EQUIVALENT

APPENDIX F

WORKING DRAWINGS FOR ANALYZER SAMPLE PROBES

(Other drawings were provided by marking up existing Mack Trucks Layout Drawings provided originally by the oven vendor; these were not reproducible.)

LEL SAMPLE LINE REQUIREMENTS - MACK TRUCKS

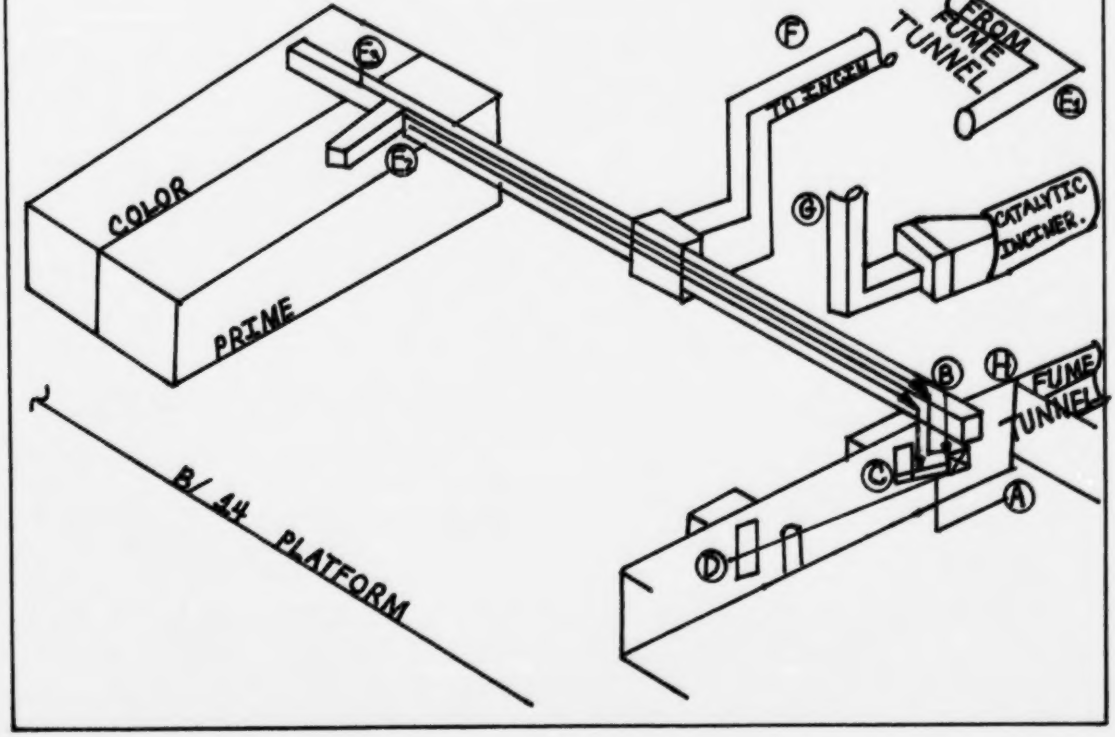
		Metal Prefilter	Bypass Type	Process Temp.	Heated Line
	Analyzer, AIT-1:				
Ⓐ	Primary D.O. Air Seal	Yes	Yes	250°F	Yes
Ⓑ	D.O. Exhaust	Yes	Yes	250°F	Yes
Ⓒ	D.O. Zone 1	Yes	Yes	250°F	Yes
Ⓓ	D.O. Zone 2	Yes	Yes	250°F	Yes
(E_1)	Fume Tunnel Exhaust	No	No	85°F	No
(E_2)	Fume Tunnel Exit	No	No	85-220°F	No
(E_3)	Fume Tunnel Auxiliary	No	No	85-220°F	No
Ⓕ	CPD Combined	Yes	No	220°F	Yes
Ⓖ	Incin. Exhaust	Yes	No	600°F	Yes
Ⓗ	Ambient	No	No	85°F	No
	Analyzer, AIT-2:				
Ⓦ	P.O. Product Inlet	Yes	Yes	250°F	Yes
Ⓧ	P.O. Exhaust	Yes	Yes	250°F	Yes
Ⓨ	C.O. Product Inlet	Yes	Yes	250°F	Yes
Ⓩ	C.O. Exhaust	Yes	Yes	250°F	Yes

D.O. - Dip-Coat Oven
P.O. - Prime Oven
C.O. - Color Oven

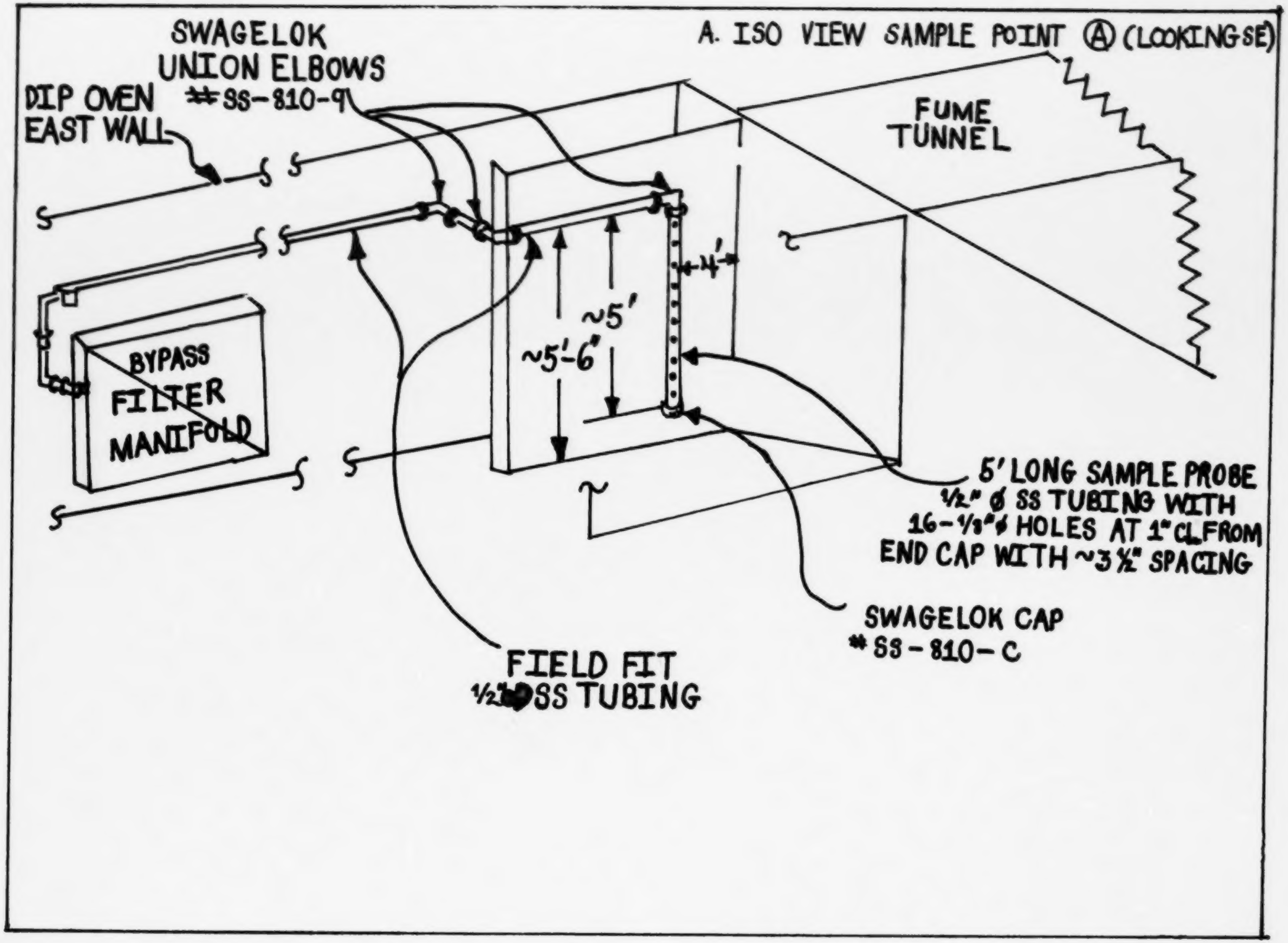
LEL Sample Line Requirements - Mack Trucks

		Metal Prefilter	Bypass Type	Process Temp.	Heated Line
A	Primary Air Seal	Yes	Yes	250°F	Yes
B	D.O. Exhaust	Yes	Yes	250°F	Yes
C	D.O. Zone 1	Yes	Yes	250°F	Yes
D	D.O. Zone 2	Yes	Yes	250°F	Yes
E_1	Fume Tunnel Exhaust	No	No	85°F	No
E_2	P.O. Exhaust	Yes	Yes	250°F	Yes
E_3	C.O. Exhaust	Yes	Yes	250°F	Yes
F	CPD Combined	Yes	No	220°F	Yes
G	Incin. Exhaust	Yes	No	600°F	Yes
H	Ambient	No	No	85°F	No

LEL Sample Line Runs - General Plan "A"

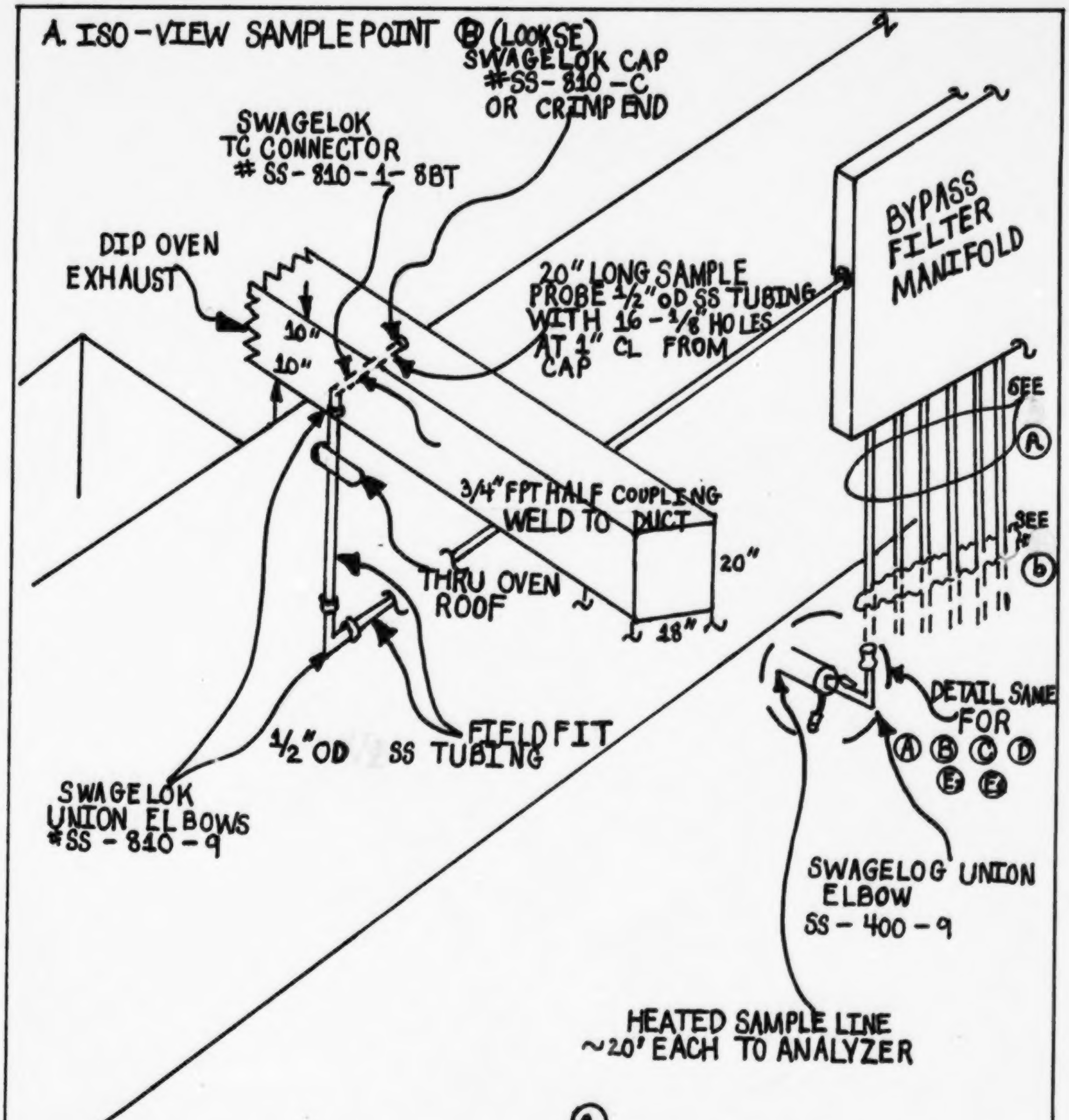


E3
E2
COLOR
PRIME
F
TO ENGIN
FROM FUME TUNNEL
E1
G
CATALYTIC INCINER.
B
H
FUME TUNNEL
C
A
D
B/ 14 PLATFORM



A. ISO VIEW SAMPLE POINT Ⓐ (LOOKING SE)

SWAGELOK
UNION ELBOWS
#SS-810-9
DIP OVEN
EAST WALL
FUME
TUNNEL
BYPASS
FILTER
MANIFOLD
~5'
~5'-6"
4'
5' LONG SAMPLE PROBE
1/2" Ø SS TUBING WITH
16-1/8"Ø HOLES AT 1" CL FROM
END CAP WITH ~3 1/2" SPACING
SWAGELOK CAP
# SS-810-C
FIELD FIT
1/2" SS TUBING

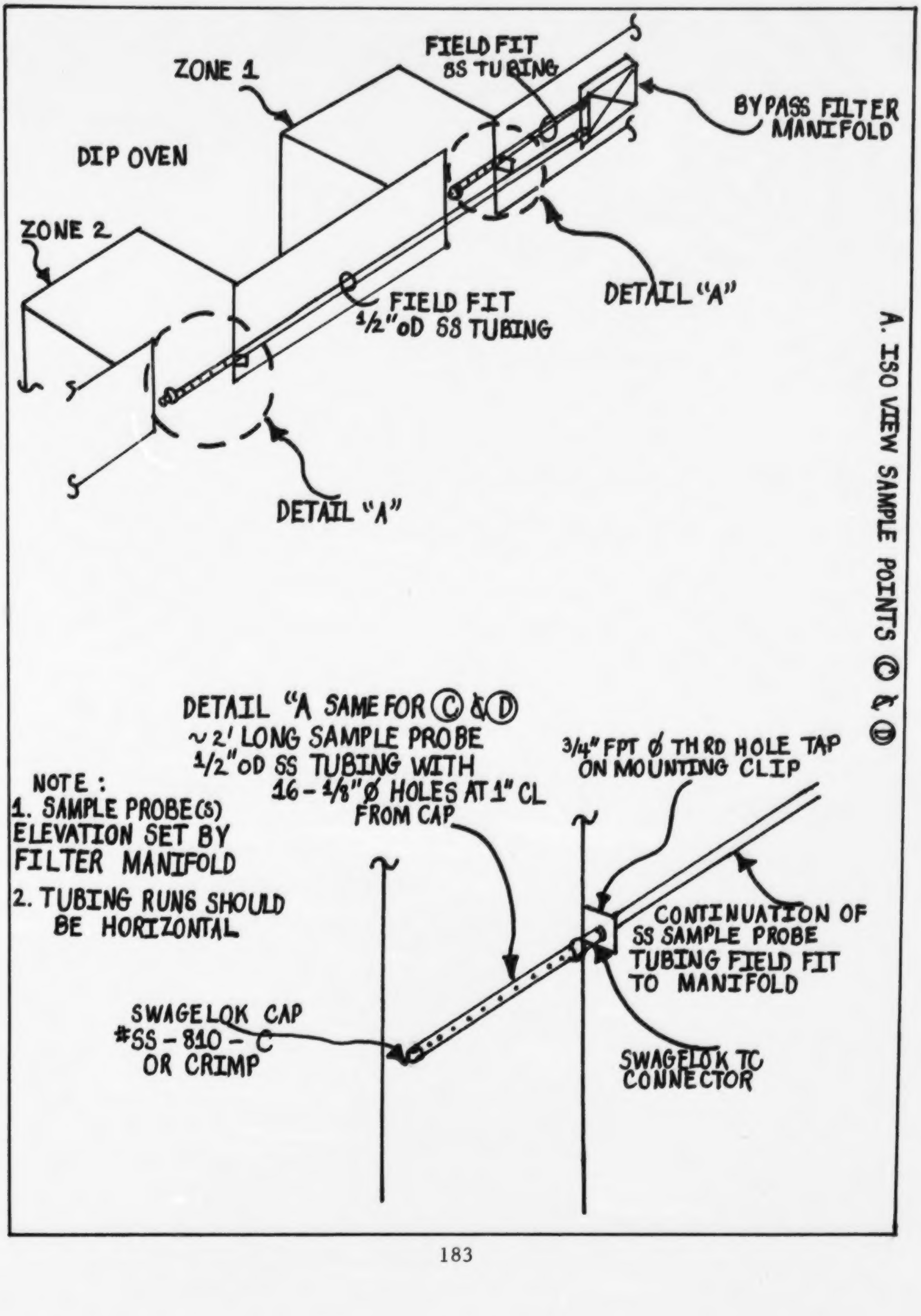

A. ISO-VIEW SAMPLE POINT Ⓑ (LOOKSE)
SWAGELOK CAP #SS-810-C OR CRIMP END
SWAGELOK TC CONNECTOR # SS-810-1-8BT
DIP OVEN EXHAUST
10"
10"
20" LONG SAMPLE PROBE 1/2" OD SS TUBING WITH 16-1/8" HOLES AT 1" CL FROM CAP
BYPASS FILTER MANIFOLD
SEE Ⓐ
SEE Ⓑ
3/4" FPT HALF COUPLING WELD TO DUCT
20"
18"
THRU OVEN ROOF
FIELD FIT
1/2" OD SS TUBING
SWAGELOK UNION ELBOWS #SS-810-9
DETAIL SAME FOR Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓔ
SWAGELOG UNION ELBOW SS-400-9
HEATED SAMPLE LINE ~20' EACH TO ANALYZER

NOTE:
1. SAMPLE PROBE IS HELD IN PLACE BY SWAGELOK TC SCREWED TO 3/4" FPT HALF COUPLING WELD TO DUCT

Ⓐ 1/4" OD SS TUBING FROM MANIFOLD

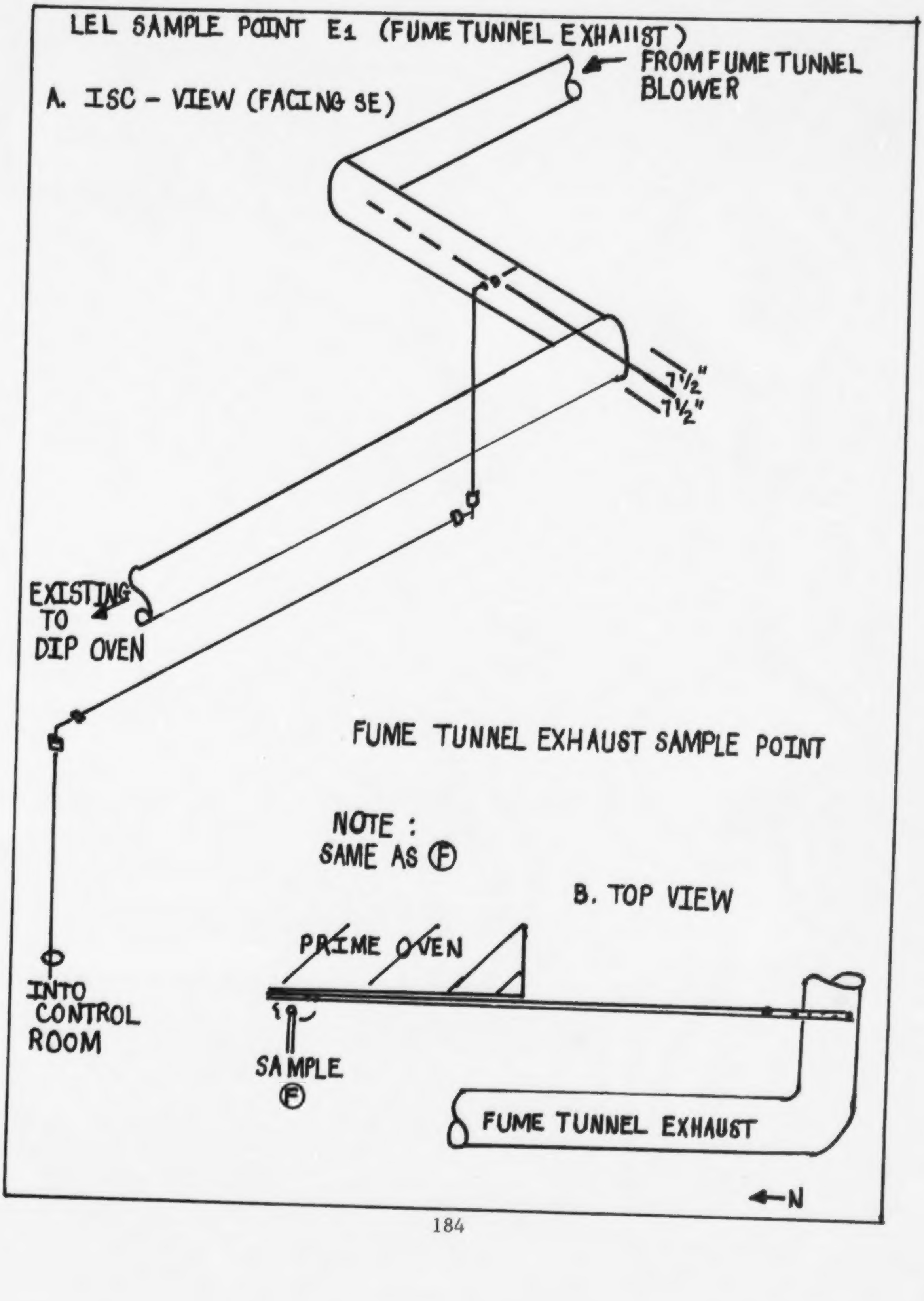
Ⓑ FIELD HOLE THRU DIP OVEN FLOOR HOLE Ø SHOULD BE MINIMIZED

DIP OVEN EXHAUST SAMPLE POINT

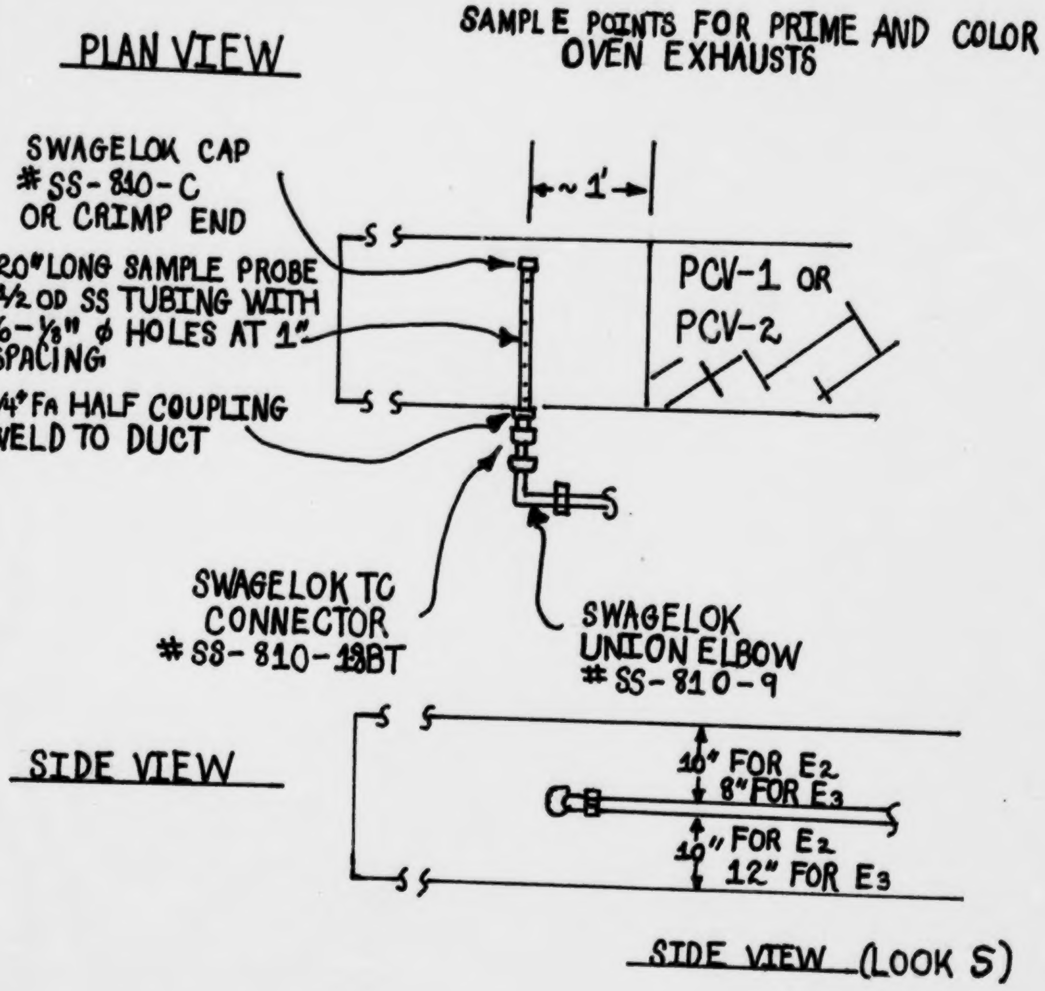


A. ISO VIEW SAMPLE POINTS Ⓒ & Ⓓ

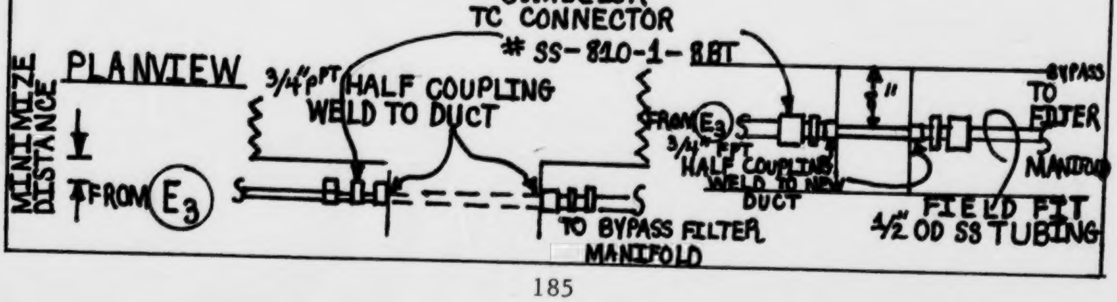
ZONE 1
FIELD FIT SS TUBING
BYPASS FILTER MANIFOLD
DIP OVEN
ZONE 2
FIELD FIT 1/2" OD SS TUBING
DETAIL "A"
DETAIL "A"
DETAIL "A SAME FOR Ⓒ & Ⓓ
~2' LONG SAMPLE PROBE
1/2" OD SS TUBING WITH
16 - 1/8" Ø HOLES AT 1" CL
FROM CAP
NOTE :
1. SAMPLE PROBE(S) ELEVATION SET BY FILTER MANIFOLD
2. TUBING RUNS SHOULD BE HORIZONTAL
3/4" FPT Ø THRD HOLE TAP ON MOUNTING CLIP
CONTINUATION OF SS SAMPLE PROBE TUBING FIELD FIT TO MANIFOLD
SWAGELOK CAP #SS - 810 - C OR CRIMP
SWAGELOK TC CONNECTOR

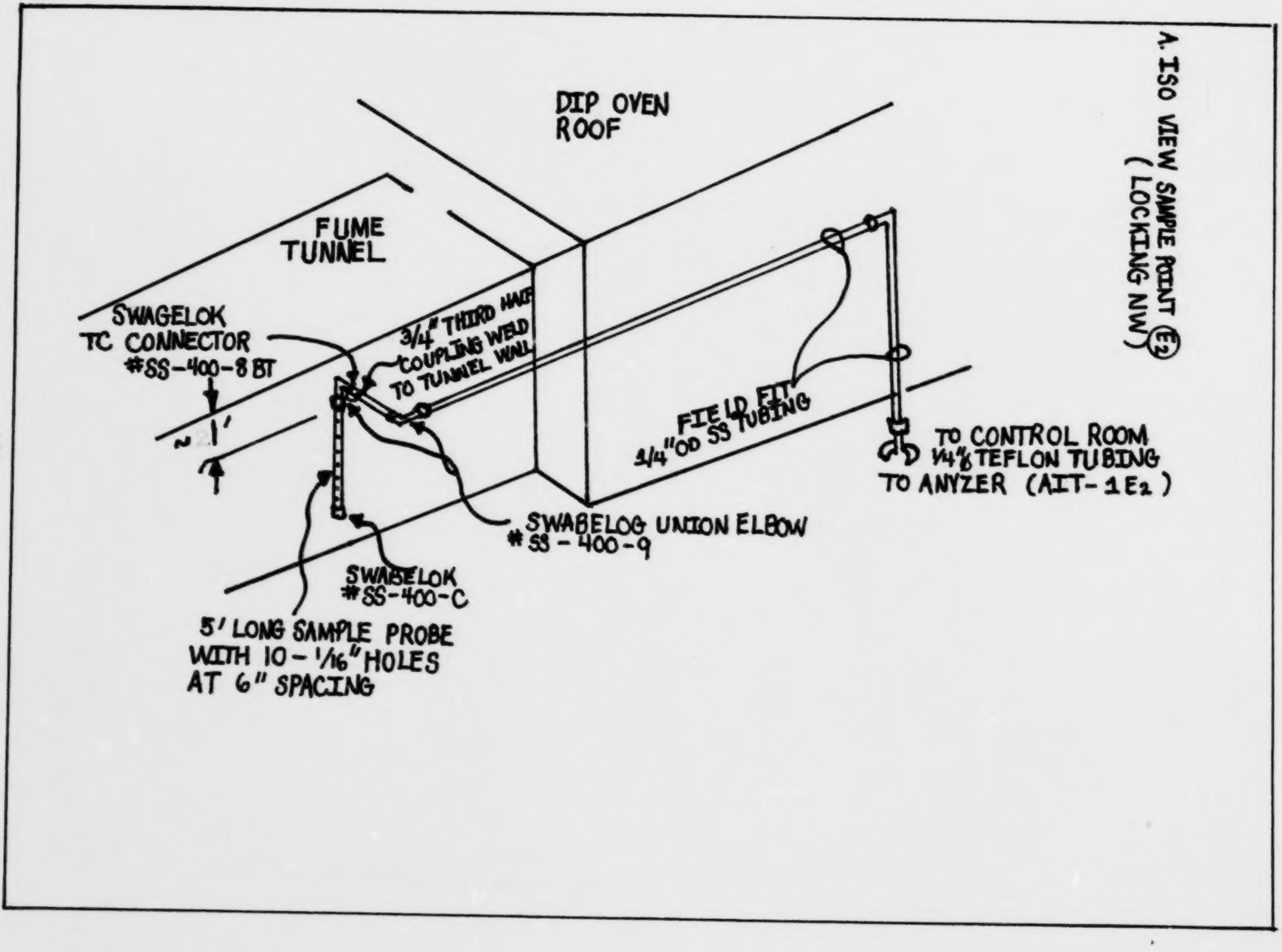

LEL SAMPLE POINT E1 (FUME TUNNEL EXHAUST)
A. ISC - VIEW (FACING SE)
FROM FUME TUNNEL BLOWER
7½"
7½"
EXISTING TO DIP OVEN
INTO CONTROL ROOM
FUME TUNNEL EXHAUST SAMPLE POINT
NOTE : SAME AS Ⓕ
B. TOP VIEW
PRIME OVEN
SAMPLE Ⓕ
FUME TUNNEL EXHAUST
←N

DETAIL "1" SAME FOR E_2 OR E_3


PLAN VIEW
SAMPLE POINTS FOR PRIME AND COLOR OVEN EXHAUSTS
SWAGELOK CAP
# SS-810-C
OR CRIMP END
~ 1'
20" LONG SAMPLE PROBE
1/2 OD SS TUBING WITH
16-1/8" ϕ HOLES AT 1" SPACING
3/4" FA HALF COUPLING
WELD TO DUCT
PCV-1 OR
PCV-2
SWAGELOK TC
CONNECTOR
# SS-810-1-8BT
SWAGELOK
UNION ELBOW
# SS-810-9
SIDE VIEW
10" FOR E2
8" FOR E3
10" FOR E2
12" FOR E3
SIDE VIEW (LOOK S)

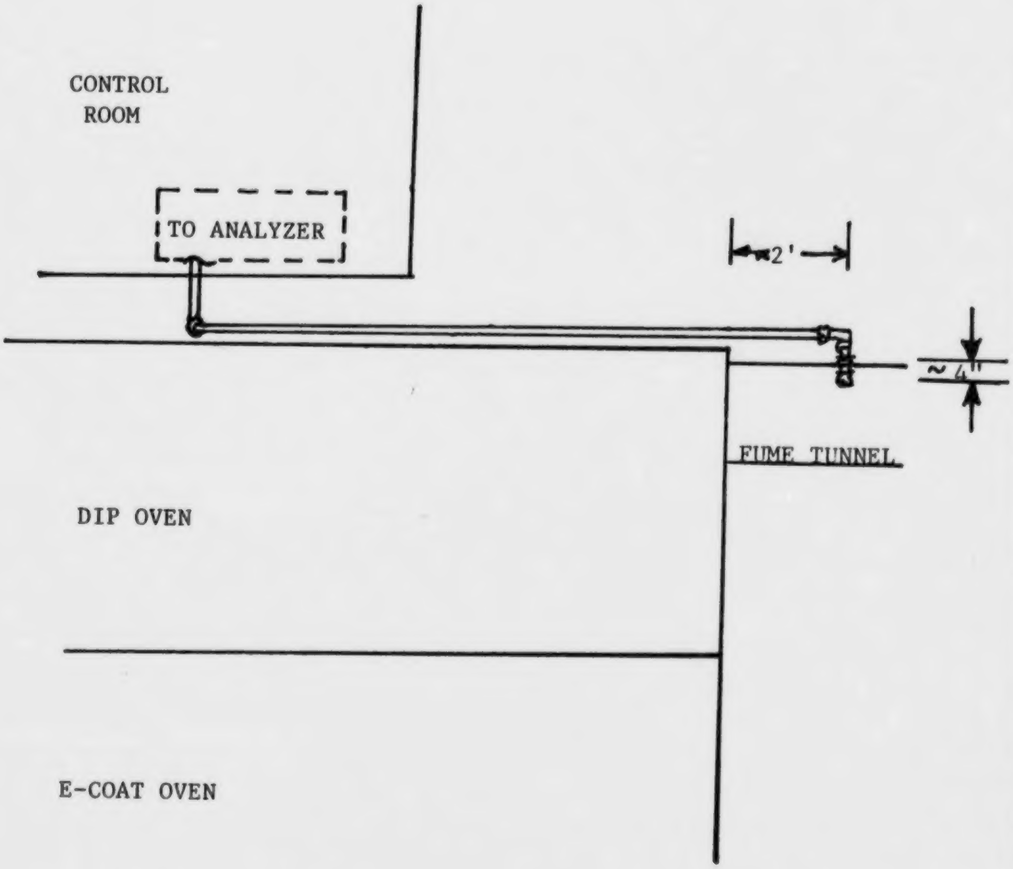
DETAIL "2" FOR E_3

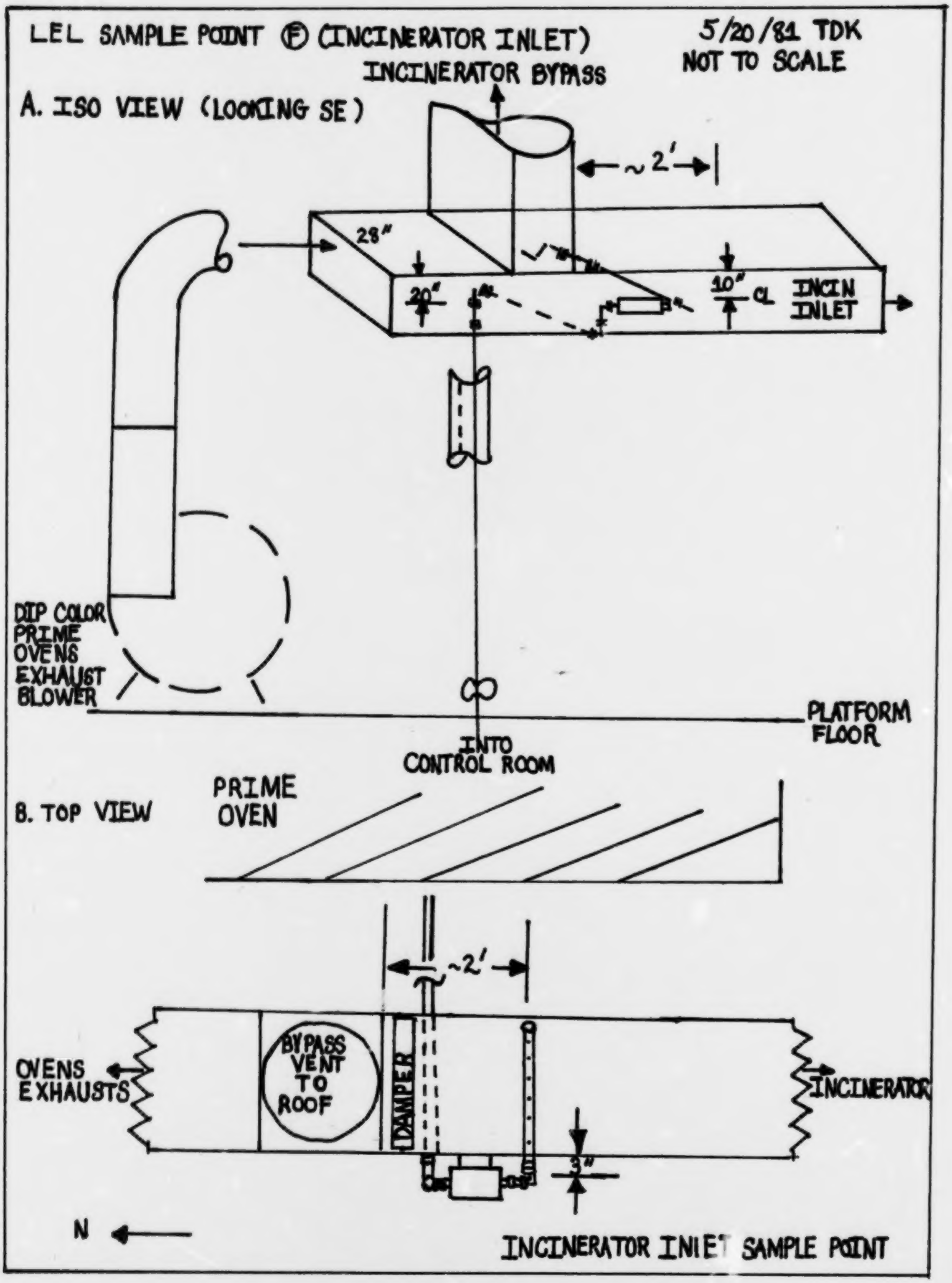

SWABELOK
TC CONNECTOR
# SS-810-1-8BT
PLANVIEW
MINIMIZE DISTANCE
FROM E3
3/4" FPT HALF COUPLING
WELD TO DUCT
TO BYPASS FILTER
MANIFOLD
FROM E3
3/4" FPT
HALF COUPLING
WELD TO NEW
DUCT
BYPASS
TO
FILTER
MANIFOLD
FIELD FIT
1/2" OD SS TUBING


A. ISO VIEW SAMPLE POINT (E2)
(LOCKING NW)

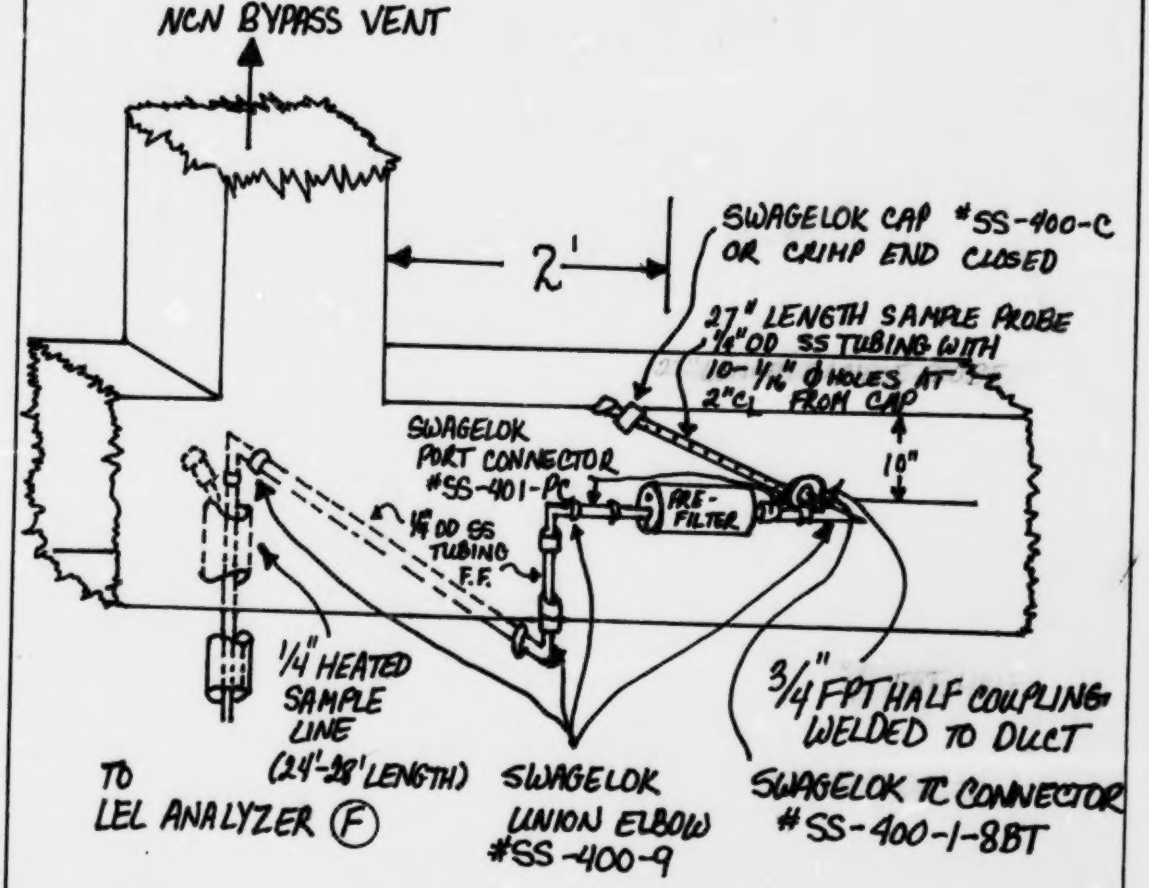
DIP OVEN
ROOF
FUME
TUNNEL
SWAGELOK
TC CONNECTOR
#SS-400-8 BT
3/4" THIRD HALF
COUPLING WELD
TO TUNNEL WALL
~2
1'
FIELD FIT
1/4" OD SS TUBING
TO CONTROL ROOM
1/4"⌀ TEFLON TUBING
TO ANYZER (AIT-1E2)
SWABELOG UNION ELBOW
#SS-400-9
SWABELOK
#SS-400-C
5' LONG SAMPLE PROBE
WITH 10-1/16" HOLES
AT 6" SPACING

B. TOP VIEW E_2


CONTROL ROOM
TO ANALYZER
2'
~4"
FUME TUNNEL
DIP OVEN
E-COAT OVEN


LEL SAMPLE POINT Ⓕ (INCINERATOR INLET)
5/20/81 TDK
NOT TO SCALE
INCINERATOR BYPASS
A. ISO VIEW (LOOKING SE)
~2'
28"
20"
10"
℄
INCIN INLET
DIP COLOR PRIME OVENS EXHAUST BLOWER
PLATFORM FLOOR
INTO CONTROL ROOM
B. TOP VIEW
PRIME OVEN
~2'
BYPASS VENT TO ROOF
DAMPER
OVENS EXHAUSTS
INCINERATOR
3"
N
INCINERATOR INLET SAMPLE POINT

C. SAMPLE LINE Ⓕ DETAILS


NCN BYPASS VENT
2'
SWAGELOK CAP #SS-400-C
OR CRIMP END CLOSED
27" LENGTH SAMPLE PROBE
1/4" OD SS TUBING WITH
10-1/16" ⌀ HOLES AT
2" ℄ FROM CAP
10"
SWAGELOK
PORT CONNECTOR
#SS-401-PC
PRE-
FILTER
1/4" OD SS
TUBING
F.F.
1/4" HEATED
SAMPLE
LINE
(24'-28' LENGTH)
TO
LEL ANALYZER Ⓕ
SWAGELOK
UNION ELBOW
#SS-400-9
3/4" FPT HALF COUPLING
WELDED TO DUCT
SWAGELOK TC CONNECTOR
#SS-400-1-8BT

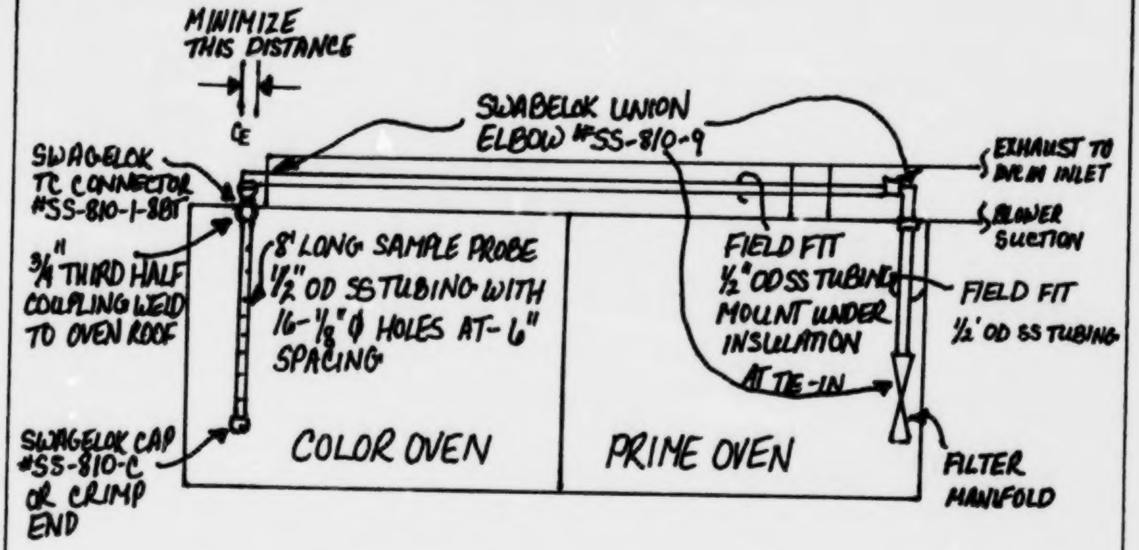
NOTES:

1. MOUNT HEATED PREFILTER HORIZONTALLY ON VENT DUCT, 3" ℄ FILTER TO DUCT WALL.
2. SAMPLE PROBE MUST BE LEVEL. THIS IS HELD IN PLACE BY THE SWAGELOK TC CONNECTOR.

INCINERATOR EXHAUST SAMPLE POINT

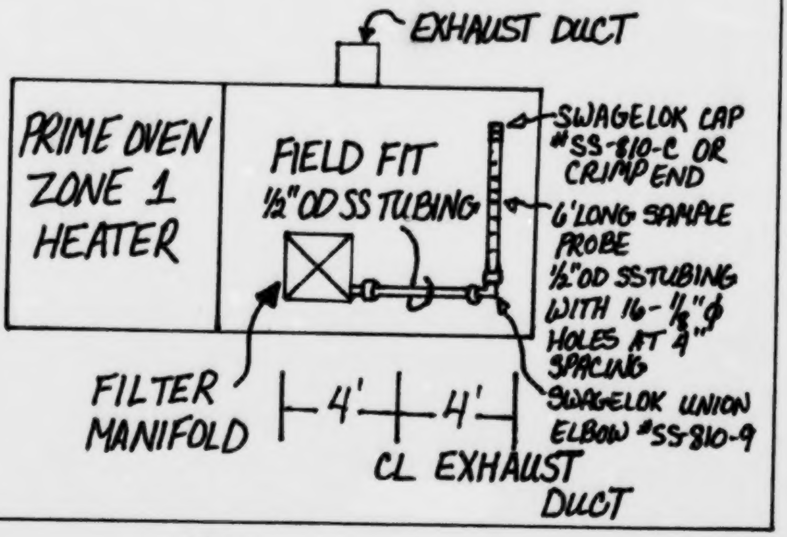
DETAIL "3" SAMPLE POINT Ⓨ

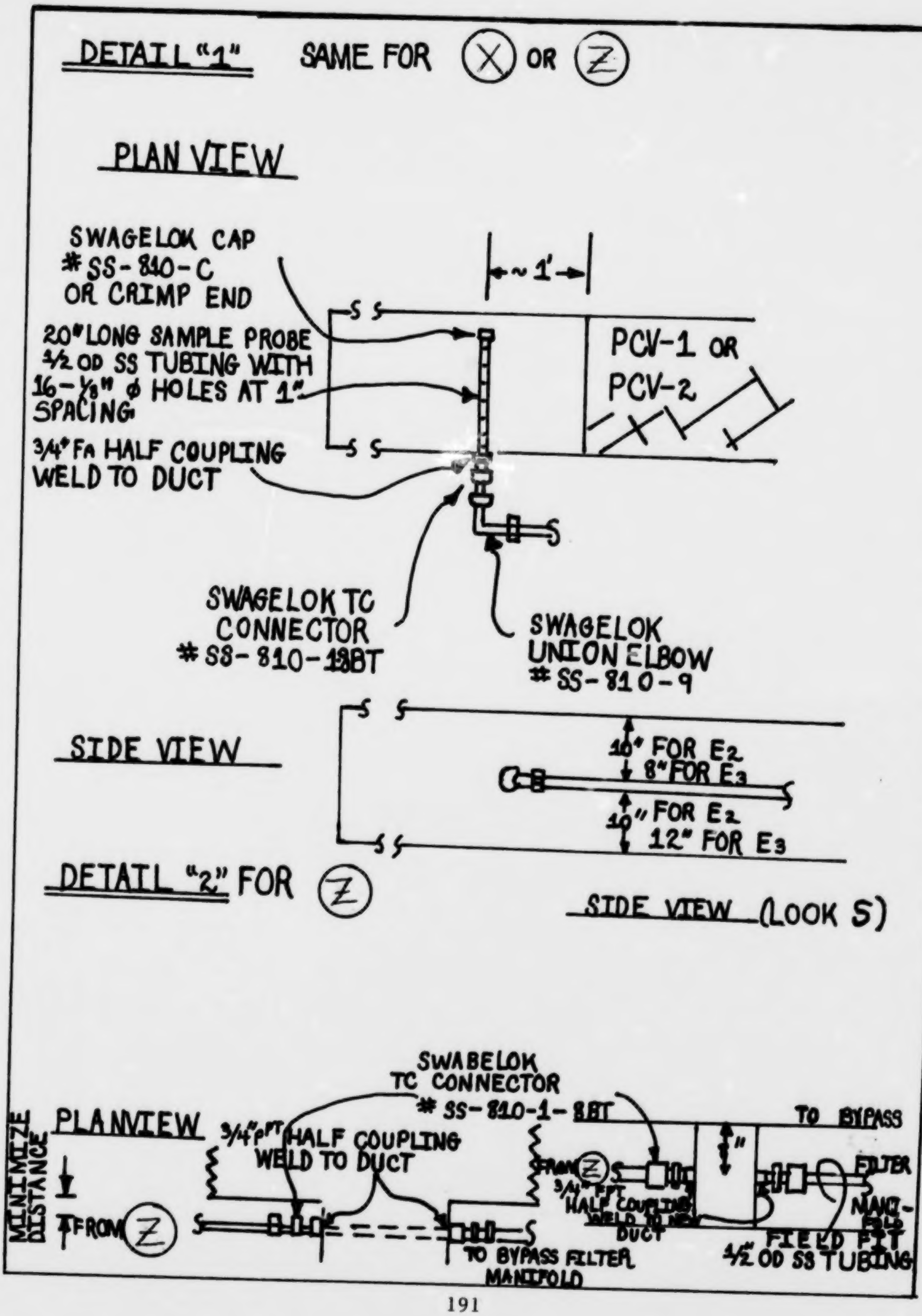
SECTION A-A VIEW (LOOKING S)


MINIMIZE THIS DISTANCE
CL
SWAGELOK TC CONNECTOR #SS-810-1-8BT
SWABELOK UNION ELBOW #SS-810-9
EXHAUST TO OVEN INLET
BLOWER SUCTION
3/4" THIRD HALF COUPLING WELD TO OVEN ROOF
8' LONG SAMPLE PROBE 1/2" OD SS TUBING WITH 16-1/8" ϕ HOLES AT-6" SPACING
FIELD FIT 1/2" OD SS TUBING MOUNT UNDER INSULATION
FIELD FIT 1/2' OD SS TUBING
AT TIE-IN
SWAGELOK CAP #SS-810-C OR CRIMP END
COLOR OVEN
PRIME OVEN
FILTER MANIFOLD

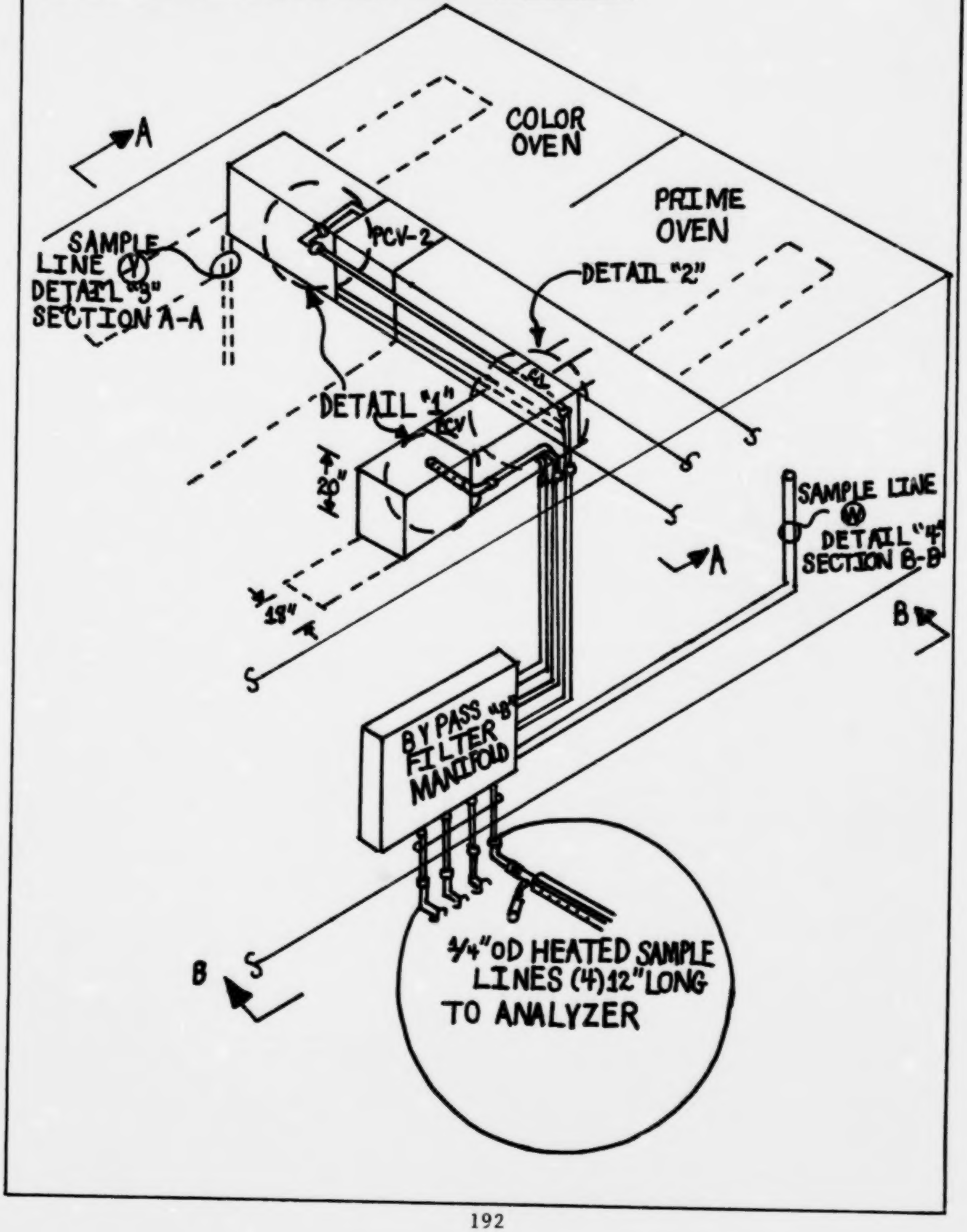
DETAIL "4" SAMPLE POINT Ⓦ

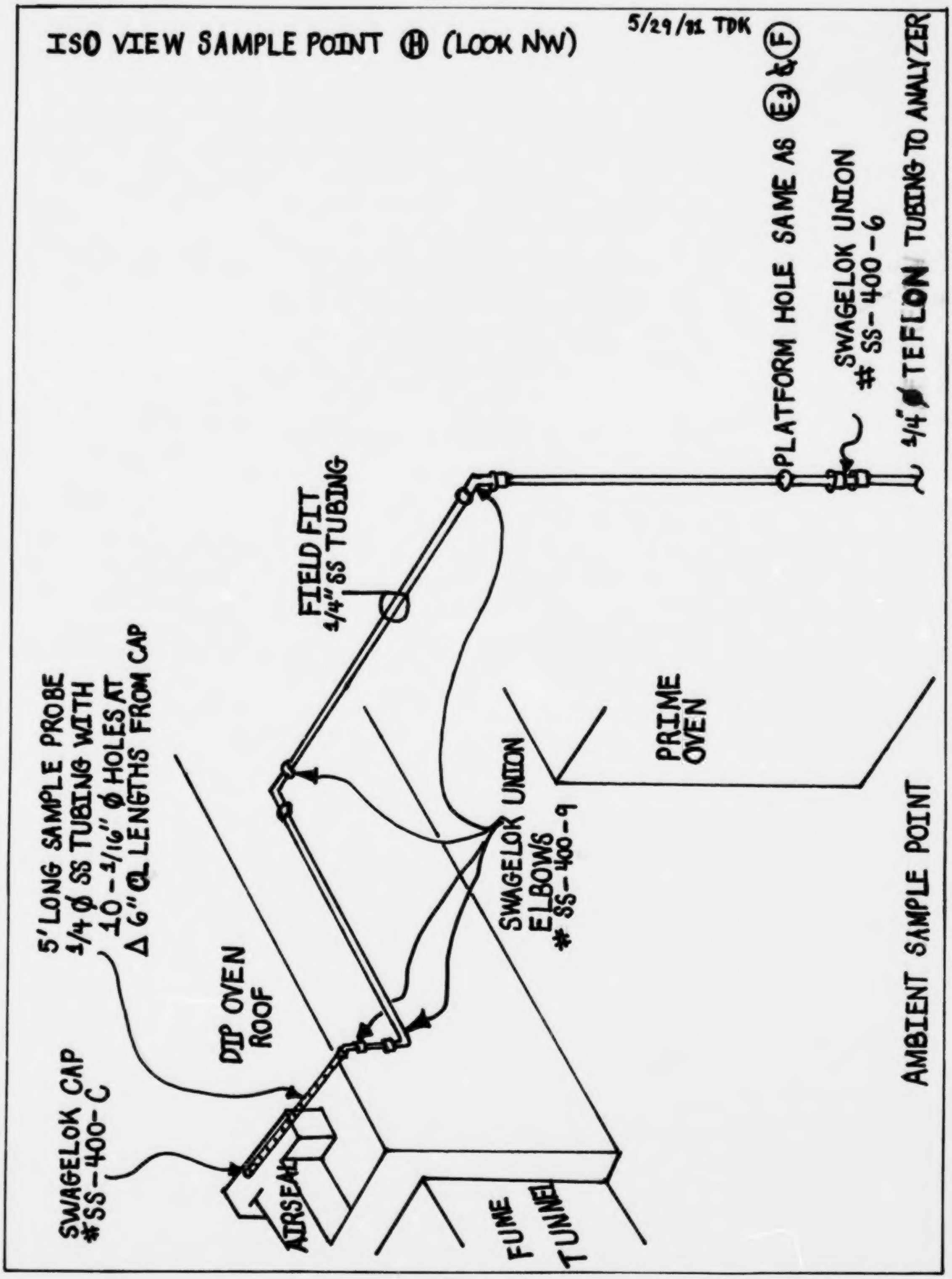
SECTION B-B VIEW (LOOKING E)


EXHAUST DUCT
PRIME OVEN ZONE 1 HEATER
FIELD FIT 1/2" OD SS TUBING
SWAGELOK CAP #SS-810-C OR CRIMP END
6' LONG SAMPLE PROBE 1/2" OD SS TUBING WITH 16-1/8" ϕ HOLES AT 4" SPACING
FILTER MANIFOLD
4'
4'
CL EXHAUST DUCT
SWAGELOK UNION ELBOW #SS-810-9


DETAIL "1" SAME FOR X OR Z
PLAN VIEW
SWAGELOK CAP
# SS-810-C
OR CRIMP END
~ 1'
20" LONG SAMPLE PROBE
1/2 OD SS TUBING WITH
16-1/8" ϕ HOLES AT 1"
SPACING
PCV-1 OR
PCV-2
3/4" FA HALF COUPLING
WELD TO DUCT
SWAGELOK TC
CONNECTOR
# SS-810-1-8BT
SWAGELOK
UNION ELBOW
# SS-810-9
SIDE VIEW
10" FOR E2
8" FOR E3
10" FOR E2
12" FOR E3
DETAIL "2" FOR Z
SIDE VIEW (LOOK S)
SWABELOK
TC CONNECTOR
# SS-810-1-8BT
TO BYPASS
PLANVIEW
MINIMIZE DISTANCE
3/4" FPT HALF COUPLING
WELD TO DUCT
FROM Z
FROM Z
3/4" FPT
HALF COUPLING
WELD TO NEW
DUCT
1"
FILTER
MANI-
FOLD
FIELD FIT
1/2" OD SS TUBING
TO BYPASS FILTER
MANIFOLD

A. ISO - VIEW SAMPLE POINTS Ⓦ Ⓧ Ⓨ & Ⓩ


A
COLOR OVEN
PRIME OVEN
SAMPLE LINE Ⓨ
DETAIL "3"
SECTION A-A
PCV-2
DETAIL "2"
C1
DETAIL "1"
PCV1
20"
18"
A
SAMPLE LINE Ⓦ
DETAIL "4"
SECTION B-B'
B
BYPASS "B" FILTER MANIFOLD
1/4" OD HEATED SAMPLE LINES (4) 12" LONG
TO ANALYZER
B


ISO VIEW SAMPLE POINT Ⓗ (LOOK NW)

5/29/81 TDK

SWAGELOK CAP
#SS-400-C
AIRSEAL
FUME TUNNEL
DIP OVEN ROOF
5' LONG SAMPLE PROBE
1/4 ϕ SS TUBING WITH
10 - 1/16" ϕ HOLES AT
Δ 6" ℄ LENGTHS FROM CAP
SWAGELOK UNION
SWAGELOK ELBOWS
# SS-400-9
PRIME OVEN
FIELD FIT
1/4" SS TUBING
PLATFORM HOLE SAME AS Ⓔ₃ & Ⓕ
SWAGELOK UNION
# SS-400-6
1/4" ϕ TEFLON TUBING TO ANALYZER
AMBIENT SAMPLE POINT

APPENDIX G

INSTRUCTION MANUAL FOR THE HYDROCARBON ANALYZERS USED AT MACK TRUCKS

SECTION 1

INTRODUCTION

1.1 GENERAL

The Ratfisch RS-555 used in this project is a multi-channel hydrocarbon analyzer designed for the continuous, simultaneous determination of the hydrocarbon concentration in sample gases from up to 8 sampling points.

This analyzer employs the flame ionization detection (FID) method of measuring hydrocarbon concentration in a sampled vapor. This method yields a signal that is in direct proportion to the hydrocarbon concentration in the sample. The measurement, therefore, is independent of the type of solvent or hydrocarbon mixture being sampled and is easily calibrated for significant changes in the composition of the sampled vapor.

The analyzer is calibrated as percent of the LEL.

1.2 FEATURES

The features of the analyzer considered important for monitoring ovens follow:

1. The analyzer detection unit is heated to prevent condensation of the sampled vapors, thus ensuring accurate readings and reliability.
2. A sintered ceramic in-line filter is also heated and provides a final filter of samples to prevent particulates from entering the analyzer.
3. Solid-state electronic units are used.

4. Front panels display percentage of the LEL; air, fuel, and sample-stream conditions; and flameout to provide another visual display of readings in addition to the CRT screen.

5. Accuracy is not affected by noncombustible compounds in the sample vapor.

6. The housing of up to four FID burners with sample handling in one analyzer detection unit reduces hardware and operating costs.

7. The analyzer analog outputs were compatible with the microcomputer.

8. Each analyzer channel, control module, and sample-handling system is functionally independent. Failure of one component would not affect the others.

1.4 SPECIFICATION

The specifications and individual performance of the analyzer follows:

1.	Analysis Method:	Flame Ionization Detection (FID)
2.	Sensitivity:	Maximum 1 ppm C_1
3.	Ranges: RS-555	Range from 0-100% of the LEL or one of the following: 0-10, 0-100, 0-1,000, or 0-10,000 ppm C_1/ channel
4.	Response Time:	Less than 1 second full-scale input
5.	Oxygen Cross Sensitivity:	Less than 1% of selected range
6.	Outputs:	0-10 V standard; 0-1 V, 0-100 mV or 0-10 mV available; 0-20 mA and 4-20 mA available
7.	Ambient Operating Temperature:	+5 to +40°C (40 to 104°F)
8.	Humidity:	95% RH, noncondensing
9.	Power Requirements:	115 VAC, 60Hz, 1800 VA

10.	Sample Display:	Analog meter in ppm of hydrocarbon or analog meter in % of the LEL
11.	Zero Adjust:	Manually on front panel
12.	Span Control:	Manually on front panel of each amplifier
13.	Calibration:	Front panel push button
14.	Burner Fuel Consumption:	Hydrogen: 20 ml/min; Hydrogen-helium 40/60 mixture: 50 ml/min per channel
15.	Ignition:	Manual from front panel
16.	Burner Air Consumption:	Oil-free air; 300 ml/min per channel
17.	Span Gas Consumption:	5 l/min during calibration

SECTION 2

OPERATION

2.1 PRINCIPLE OF OPERATION AND DESCRIPTION

The two major elements of the hydrocarbon analyzer are the electronics unit and the analyzer detection unit. The FID burner and sample-handling systems are integrated into the analyzer detection unit.

This analyzer included two oven detection units containing four FID burners. Two cabinet mounted analyzers are supplied. In one cabinet, two oven detection units, one electronics module and electronics controls for the heated sample lines were assembled. Each oven detection unit includes four flame ionization detectors, each one controlled from a separate electronics module in the electronics unit. The second cabinet assembly included one oven detection unit with four flame ionization detectors and one electronics unit with four electronics modules.

The flow diagram for one detector in the analyzer detection unit is shown in Figure 1. Four gaseous streams enter this unit. The flow rates of each gas are controlled for continuous metering with pressure regulators and capillaries. Sample gas, fuel, and air are continuously metered to the FID burner during operation. A positive displacement diaphragm pump is used in conjunction with a pressure regulator and capillary to ensure constant flow rates and pressure control to the FID burner(s).

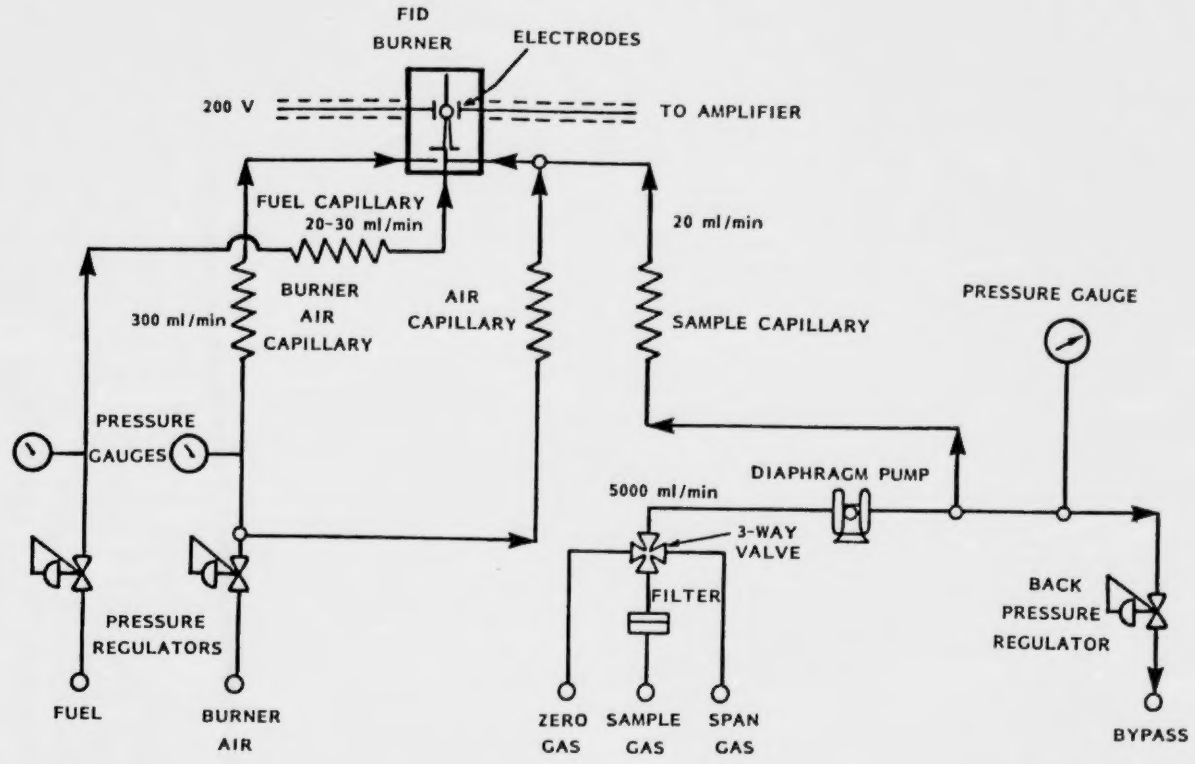

FID
BURNER
ELECTRODES
200 V
TO AMPLIFIER
FUEL CAPILLARY
20-30 ml/min
20 ml/min
300 ml/min
BURNER
AIR
CAPILLARY
AIR
CAPILLARY
SAMPLE CAPILLARY
PRESSURE GAUGE
PRESSURE
GAUGES
DIAPHRAGM PUMP
5000 ml/min
3-WAY
VALVE
FILTER
BACK
PRESSURE
REGULATOR
PRESSURE
REGULATORS
FUEL
BURNER
AIR
ZERO
GAS
SAMPLE
GAS
SPAN
GAS
BYPASS

Figure 1. Analyzer Detection Unit Flow Diagram

Calibration required zero gas (usually oil-free air) and span gas (usually 1,000 ppm propane-air or propane-nitrogen mixture). These gases share the same sample line as the sample stream. Push button solenoid valves provide for the selection of sample, zero, or span gases.

For each model, the electronics unit contains all the circuitry required to condition the signal from the FID burner before output. A high input impedance amplifier converts the low signal current produced by the ionization process to a level suitable to drive meters, chart recorders, alarms, and controllers. The electronics unit also contains the power supply.

2.2 INSTALLATION

The services necessary for analyzer operation are:

- Hydrogen Burner Fuel
- Burner Combustion Air
- Zero Air
- Flush Air
- Span Gas as specified for the application
- Electric Power Supply 110 VAC, 60 Hz

The hydrogen and air supplies should have less than 1 ppm total hydrocarbon content, except the flush air which must be free of oil and water. The gas connections between the hydrogen generator, gas cylinders and the analyzer were made with new teflon tubing (1/4"). During the assembly of the gas connections and gas regulators extreme care must be taken to ensure that no dirt, oil or grease is introduced into the system.

1. Install power cable to the analyzer
2. Attach electrical connections between analyzer detection unit(s) and electronics unit
3. Connect analyzer output cable to recorder or controller (see pin connection diagram)

4. Connect analyzer alarm contacts, if required according to pin connection diagram.

Analyzer is ready for operation.

Installation Concerns:

1. Analyzer Detector Unit oven temperature should be minimized to extend sample pump and valve diaphragm life.
2. Sample bypass and FID burner discharge must not be piped to add sample system back pressure.
3. The FID "combustibles" discharge will contain $H_2O(l)$ therefore these lines must always slope down to drain.

2.3 START-UP, CALIBRATION, ALARM SETTING

Heatup

1. Flush air:
The pressure regulator at the rear of the detector unit(s) should be set to 0.5 bar outlet pressure. (Gauge is located on front panel of unit). This is a one time setting.

2. Switch on "power."

3. Switch on detector unit heater switches. During the heat-up phase the switch lamp(s) burn(s) brightly. Once operational temperature has been reached the lamp burns less brightly and flickers.

The detector unit temperature can be set from the front panel of the control unit by means of the recessed potentiometers. The detector unit temperature read out is located on the front panel of each unit.

Gas Pressures

4. During the heat-up phase the gas supplies should be opened and pressures set. Line outlet pressure for hydrogen and combustion air should be 3 Bar. The exact operating pressures are shown on the data sheet supplied with each analyzer.

Ignition

5. After a sufficiently long flushing period (especially necessary with hydrogen) the detectors, or FID's, can be ignited. The ignition of the individual detectors is accomplished by switching the FID selection switch to the corresponding FID number; in this

position the FID signal is connected to the analog meter on the electronics unit.

To observe the ignition easier, span gas is also switched on. The span gas is then automatically switched via solenoid valves to the FID which has been selected with the selection switch.

The cylinder outlet pressure for span gas must not exceed the sample pressure specified in the Data Sheet (this pressure is normally 0.1 to 0.2 Bar).

Before ignition, reduce the combustion air pressure to about 0.4 Bar, then press the red ignition button on the amplifier module corresponding to the selected FID. When the detector has ignited a constant signal will be seen on the analog meter and on the LED digital display.

Should the signal remain at zero then increase the hydrogen pressure to 0.5 Bar and repeat the ignition procedure. After successful ignition the remaining detectors can be ignited, each with its own ignition button and the successful gas mixture used to ignite the first detector. When all detectors are ignited the hydrogen and combustion air pressure can be set to the specified values.

To optimize the fuel/air ratio, adjust the fuel pressure to generate the maximum indication of percent LEL for calibration (or span) gas. This adjustment needs only to be made once to optimize all channels.

Pumps

6. The sample pumps may now be turned on. As the pumps are turned on, observe the sample pressure gauges. A pressure of 250 mB must not be exceeded. The sample pressure for each channel can be independently controlled. To change the pressure insert a screwdriver in the hole above the sample pressure gauge where the sample back pressure regulator is located. Turn clockwise to increase pressure and counter clockwise to decrease pressure.

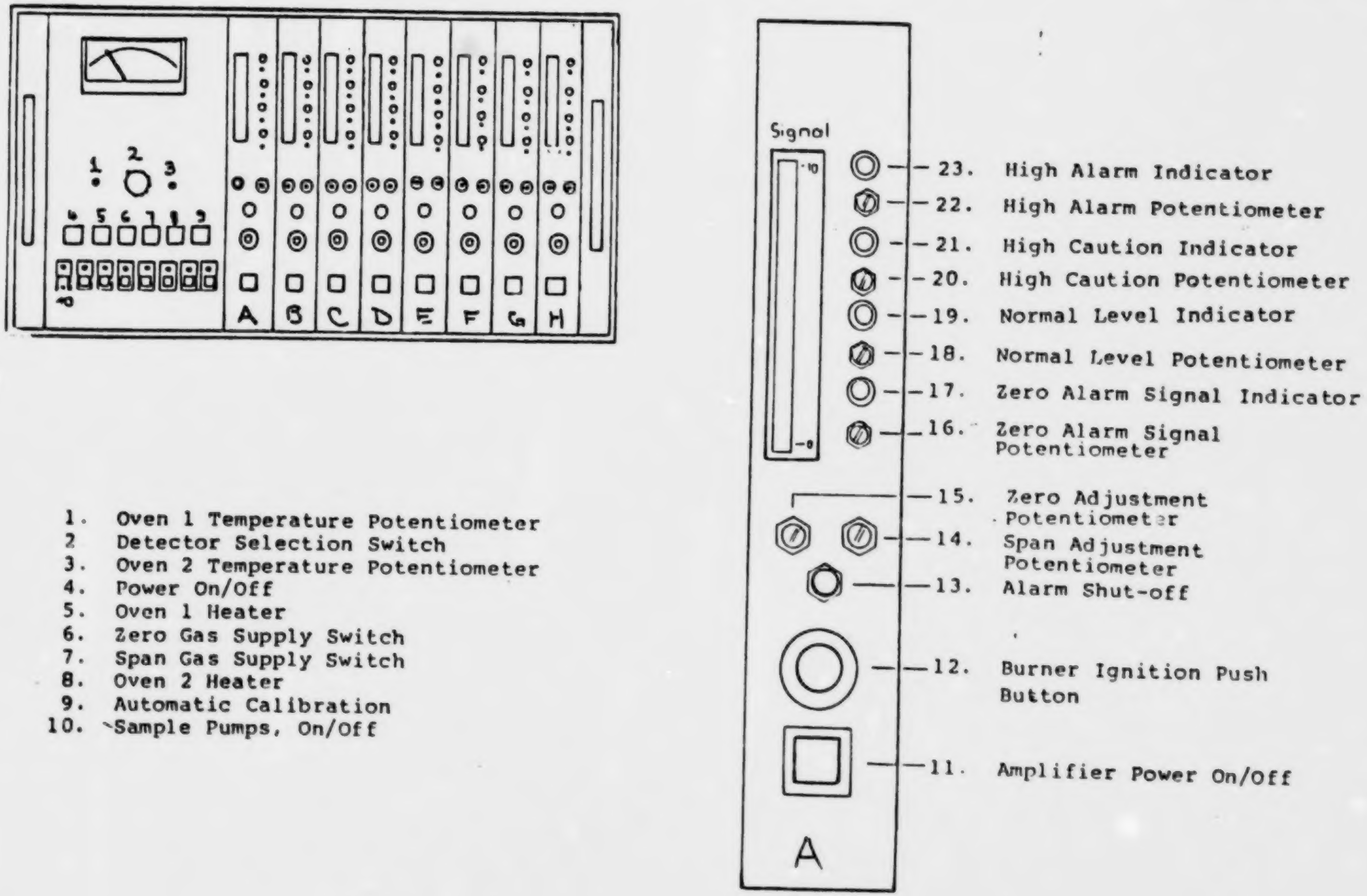
Refer to Figure 2

To calibrate each detector channel:

1. Dial selector switch, item #2, to desired detector channel (A through H).
2. Press zero (null) gas supply switch, item #6.
3. Read analog meter and adjust "zero" potentiometer set screw, item #15, to result in zero meter reading.
4. Press span gas supply switch, item #7.
5. Read analog meter and adjust span potentiometer set screw, item #14, to result in meter reading equal to span gas.
6. Repeat steps 1 to 5 for each detector channel.

To set alarm levels:

1. Disconnect detector signal plug (HF - Buchse) from analyzer electronics unit to eliminate electrical interference.
2. Adjust "zero" potentiometer set screw, item #15, to near zero digital meter signal.
3. Adjust "zero alarm" potentiometer set screw, item #16 to just activate the zero signal indicator light, item #17.
4. Adjust "zero" potentiometer set screw to "normal" level digital meter reading (35% of the LEL).
5. Adjust "normal" level potentiometer set screw, item #18, to just activate "normal" level indicator light, item #19.
6. Adjust "zero" potentiometer set screw to "high caution" level digital meter reading (45 % of the LEL).
7. Adjust "high caution" potentiometer set screw, item #20 to just activate "high caution" indicator light, item #21.
8. Adjust "zero" potentiometer set screw to "high alarm" level digital meter reading (50% of the LEL).
9. Adjust "high alarm" potentiometer set screw, item #22, to just activate "high alarm" indicator light, item #23.
10. Reconnect detector signal plug.


1
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3
4
5
6
7
8
9
10
A
B
C
D
E
F
G
H
Signal
10
0
23. High Alarm Indicator
22. High Alarm Potentiometer
21. High Caution Indicator
20. High Caution Potentiometer
19. Normal Level Indicator
18. Normal Level Potentiometer
17. Zero Alarm Signal Indicator
16. Zero Alarm Signal Potentiometer
15. Zero Adjustment Potentiometer
14. Span Adjustment Potentiometer
13. Alarm Shut-off
12. Burner Ignition Push Button
11. Amplifier Power On/Off
A
1. Oven 1 Temperature Potentiometer
2 Detector Selection Switch
3. Oven 2 Temperature Potentiometer
4. Power On/Off
5. Oven 1 Heater
6. Zero Gas Supply Switch
7. Span Gas Supply Switch
8. Oven 2 Heater
9. Automatic Calibration
10. Sample Pumps, On/Off

Figure 2 Analyzer Electronics Unit Front Panel and Module Details

To determine optimum Analyzer Detector Unit oven temperature:

1. Push oven 1 & oven 2 heater switches, item #5 and #8, to activate heaters.
2. Adjust oven 1 temperature potentiometer, item #1, to set unit temperature at 180°C or the curing oven temperature whichever is lower.
3. Allow unit to stabilize at set temperature.
4. Disconnect heated sample line from the Analyzer Detector Unit oven 1.
5. If disconnected sample line reading goes immediately to zero, the set temperature is alright.
6. If reading falls slowly to zero, increase temperature by 25°F increments and recheck steps 1 & 2.
7. Repeat steps 2 to 6 for Analyzer Detection Unit oven 2.

2.4 DATA SHEETS

The following data sheets are supplied for operation of the RS-555/8 and RS-555/4 hydrocarbon analyzers.

DATA SHEET

Ratfisch RS-555/8 Analyzer A - H

Prior Coated Metal - Allentown

Ser. no.: 2/26/82

Housing:	19" Rack Mount in Cabinet
Signal Output:	+ 10 V
Power Supply:	115 VAC, 60Hz
Temperature:	180°C (356°F)
Pressures:	
sample	200mBar
fuel	0.3 Bar
air	0.7 Bar
flush air	0.5 Bar
Calibration gas:	0.96 vol % C_3H_8 in N_2 or Air (40% of the LEL)

DATA SHEET

Ratfisch RS-555/4 Analyzer X - Z

Mack Trucks, Inc.

Ser. no.: 7/30/81

Housing:	19" Rack Mount in Cabinet
Signal Output:	+ 10 V
Power Supply:	115 VAC, 60Hz
Heated Sample Line:	X - Z

Temperature:	120°C
Pressures:	
sample	200mbar
fuel	0.3 bar
air	0.7 bar
flush air	0.5 bar

Calibration gas:	8000 ppm CH_4 in N_2

3.1 RECOMMENDED SPARE PARTS

The following analyzer parts are the recommended for on-site stock for the RS-555 hydrocarbon analyzer:

Recommended Quantities	Part Number	Description
1	5-4001	Op Amp, AD523JA,
1	003B	Oven Temp. Controller
1	126A	Power Supply Card
1	N/A	Channel Amplifier Card
2	5-2515/1	Pump Diaphragm
1	5-2515/2	Pump Valve
2	5-1018	Glow Plug w/Connector
2	5-1035	In-line Filter
1	5-3725	HF Connector, small hole
1	5-1019	Detector Jet

APPENDIX H

START-UP INSTRUCTIONS FOR COMPUTER CONTROL SYSTEM

MICROCOMPUTER CONTROL SYSTEM

MACK TRUCKS

APPLICABLE MANUALS

Intel Manuals

a) iCS 80 Industrial Chassis Hardware Reference Manual, Manual Number 9800799-02

b) iSBC 640 Power Supply Hardware Reference Manual, Manual Number 9800803-1

c) iSBC 86/12A Single Board Computer Hardware Reference Manual, Manual Number 9803074-01

d) iSBC 534 4-Channel Communications Expansion Board Hardware Reference Manual, Manual Number 9800450-02

e) iSBC 732 Combination Analog Input/Output Board Hardware Reference Manual, Manual Number 9800487-02

f) iCS 910 Analog Signal Conditioning/Termination Panel Hardware Reference Manual, Manual Number 9800800A

g) iCS 930 AC Signal Conditioning/Terminator Panel Hardware Reference Manual, Manual Number 9800802A

Others

a) Digital Pathways TCU-410 Timing Control Unit

b) The Intecolor User's Manual for 8000, 8300 and 8900 Series Intercolor Terminals #999203 3/14/80

c) Instruction Manual ELHYGEN Hydrogen Generator Mark V Laboratory Data Control # 870047 Rev A 8/79

d) TI Model 810 Printer Operating Instructions TI Manual No. 994353-9701

e) TI Model 810 Printer Maintenance Instructions

Computer System Start-up

To start the computer system from a powered down condition, the following steps should be taken in order:

1. Insure that all hydrocarbon analyzer channels are operational and calibrated as specified in the analyzer start-up instructions.

2. Turn the printer on. The switch is on the back of the printer next to the power cord. A red light on the front panel should now be on, so press the button labeled "on line" which will activate a second red indicator. If you have any difficulties, consult the TI OMNI 810 PRINTER manual.

3. Turn on the ISC color terminal by pressing the rocker switch located on the back of the terminal next to the power cord.

4. Make sure that the key switch in the computer chassis is off, then turn on the main power breaker in the back of the computer cabinet. After opening the rear door, the switch can be seen near the bottom.

5. There is a connector on the CPU board which must be removed before turning on the computer power or reseting the computer. The CPU board is the far right hand board in the computer chassis. It has two edge connectors: a small one near the top of the board and a larger one on the edge of the board a few inches down from the first. Remove this second connector and turn the key switch on the computer chassis to the "on" position. The CRT should say "up" briefly and then begin displaying the status screen.

6. Plug the connector back onto the CPU board. Notice the labeling and insure that the connector is right side up.

   Caution:

   Failure to remove this connector before power up will result in the conveyor being temporarily turned off. The horn will also sound briefly. Failure to replace the connector will result in improper operation of the safety warning system.

The CPS oven control system should now be fully operational. To place the system into the controlled mode, please see the operating instructions.

COMPUTER CONTROLLER OPERATION

Once the control system has been powered up, the CRT display and the printer will show all current alarm conditions. The alarm horn will be off and the system will be in the monitor mode. At the bottom of the status screen will be a short menu with the following choices:

To Turn On The Dip Oven Control - Press 1
Dip Oven To Manual Control - Press 2
To Turn Off The Alarm Horn - Press 3
To See The Menu - Press 4

To place the system in automatic control, press the number 1 key, wait for the computer to highlight your selection on the screen, and then press the key labeled "Return."

> Caution: If there are any alarm conditions present which could affect the ability of the computer to safely control the system, the alarm horn will sound and the computer will not take control.

If all is well with the world, once you press the "Return" key, the label by the "dip oven controller status" title will change from a blinking red and white "Monitor" to a soothing blue and white "Auto." The computer is now in complete control of the oven dilution air flows.

To place the system back into monitor mode simply press the number 2 key, wait for the computer to highlight the selection, and then press the key labeled "Return." The dip oven control status will revert to its blinking red and white "Monitor" display. This indicates that although the computer is not controlling the air flow, it is still monitoring and displaying all temperatures, pressures, and solvent concentrations.

If an alarm occurs which does not require immediate attention, the flashing light on the outside of the control room will come on. If the problem goes away, the computer will turn the light off. If no one fixes the problem within five minutes, the computer will turn the light off anyway.

Conditions may occur, such as failure of the hydrogen generator, which force the computer to take itself off of automatic control. Whenever this happens the alarm horn will sound. It may be temporarily silenced by turning off the disable switch on the outside of the control room. Once the alarm sounds, the alarm status column of the CRT display will not change until the horn is deactivated from the keyboard. The operator will then know which alarm occured. For example, if a high solvent alarm occurs (concentration greater than 50 percent of the LEL) the computer will open all dampers and cease automatic control. With the dampers open, the high solvent concentration may be reduced before an operator can examine the CRT screen. However, until he presses the number 3 key and the "Return" key, the screen will indicate where the problem occured. Once the horn has been reset from the keyboard using the above sequence, the disable switch outside the control room should be turned back on.

Other system functions may be accessed through the main menu. Pressing the number 4 key, waiting for the computer to highlight the selection, and then pressing the "Return" key will diplay the menu on the CRT.

Main Menu

There are five choices on the Menu:

To Display Status Screen - Press 1
To Set System Clock - Press 2
To Set Control Constants - Press 3
To Print a Summary Report - Press 4
Bull Dog - Press 5

If a selection is not made within 20 seconds, the status screen will be displayed again. Pressing the number 1 key and the "Return" key will also display the status screen.

The system clock may be changed only while not on automatic control. This is a password access screen and may only be used if the operator knows the correct password. The directions are given on the CRT screen as you go.

The only control constants which should be changed after start up are the report data initialization and printing times. The control constant screen is also password access. To skip over values that you do not wish to change, simply press the "Return" key until the curser is next to the value that is to be changed.

The computer will automatically print a summary report once per day at the time specified in the control constant screen. If an intermediate report is desired, simply press the number 4 key (while the Main Menu is on the CRT), wait until the selection is highlighted, then press the "Return" key.

Note: For a report to print, the "On-line" light on the printer must be on.

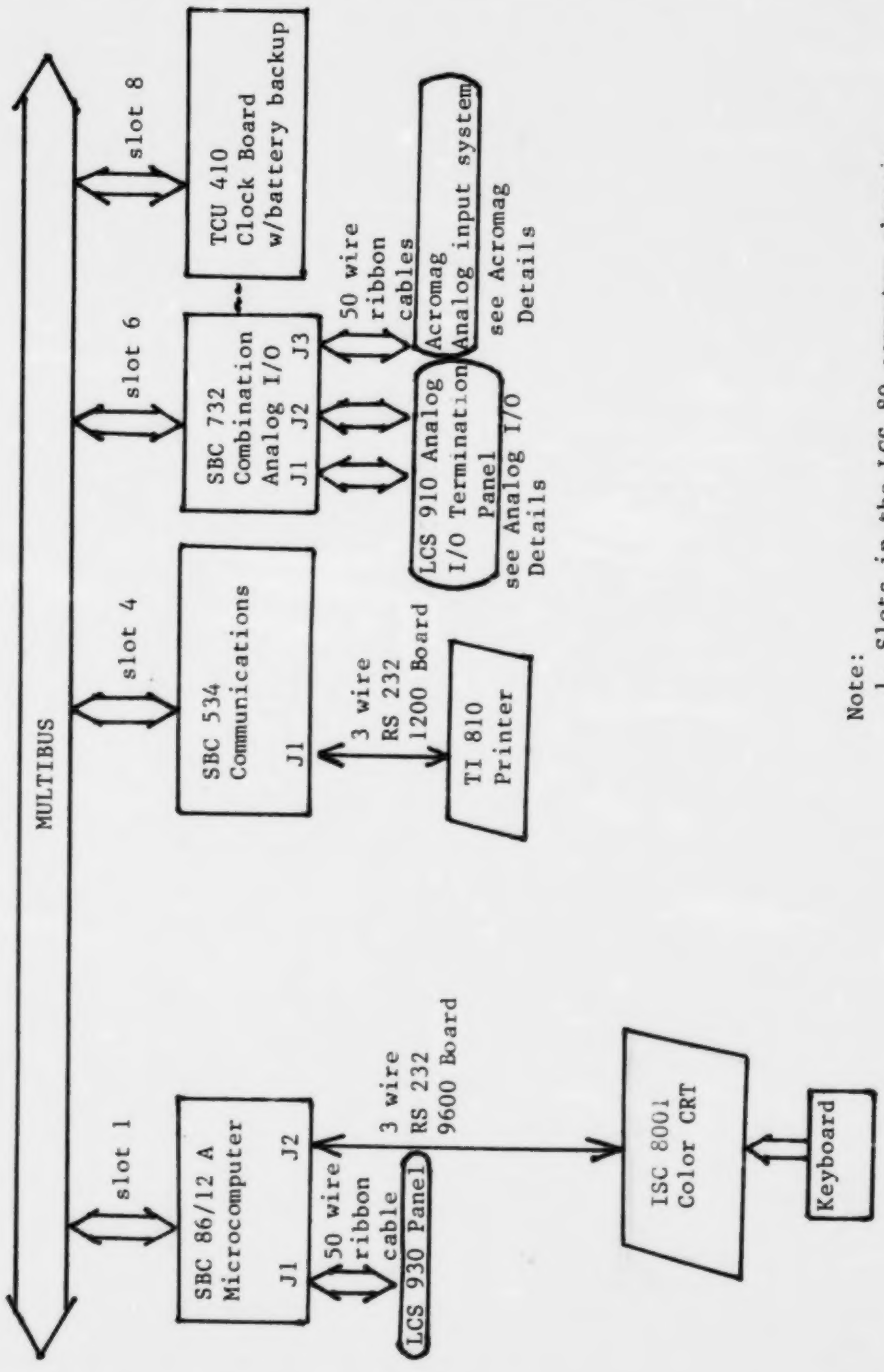
The only keys on the keyboard which can foul up the display (they don't affect the computer) are the keys labeled "CPU Reset" and "Attn Break." If one of these keys is accidentally pressed, perform the following sequence in order:

1. Press the key on the keyboard labeled "CPU Reset"
2. Press the key labeled "(ESC)"
3. Press the key labeled "F"
4. Press the key labeled "Return"
5. Press the key labeled "4"
6. Wait for the Menu to show up on the CRT
7. Press the key labeled "Return"
8. You should now see the Main Menu and can proceed as usual

APPENDIX I

MICROCOMPUTER CONFIGURATION
FOR
MACK TRUCKS, INC.

Mack Trucks Controller | Computer Block Diagram


MULTIBUS
slot 1
slot 4
slot 6
slot 8
SBC 86/12 A
Microcomputer
J1
J2
50 wire
ribbon
cable
LCS 930 Panel
3 wire
RS 232
9600 Board
ISC 8001
Color CRT
Keyboard
SBC 534
Communications
J1
3 wire
RS 232
1200 Board
TI 810
Printer
SBC 732
Combination
Analog I/O
J1 J2 J3
LCS 910 Analog
I/O Termination
Panel
see Analog I/O
Details
50 wire
ribbon
cables
Acromag
Analog input system
see Acromag
Details
TCU 410
Clock Board
w/battery backup

Note:
1. Slots in the LCS 80 computer chassis
are numbered from right to left.

Intel Microcomputer Configuration SBC 86/12 A (pg. 1)	10/9/81	KLH

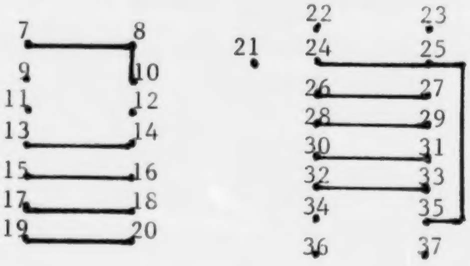
I. Parallel I/O Ports

Port CA- Output (latched)

Port C8- Input

Install N7437 in sockets A12 and A13

Wire Wrap Pins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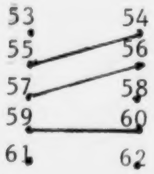
For Prom Burning a) Add jumpers to 9-23 12-37

b) Install N7437 in socket

Install IK resistor pack in socket

II. Serial I/O and Timers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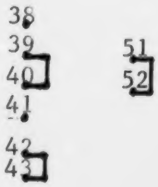
54-55 connects 1.23 MHZ to Timer 2 (9600 Baud)

56-57 connects 1.23 MHZ to Timer 0

59-60 connects 153.6 KHZ to Timer 1


38
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43
51
52

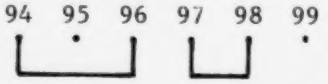
51-52 connects CTS to RTS

Intel Microcomputer Configuration SBC 86/12 A (pg 2) | 10/9/81 KLH

III. RAM OFFSET and EPROM Configuration (32K ram available to Multibus)

a) 8K EPROM (4-2716) (High Ram address 09FFF)

Wire Wrap 127-128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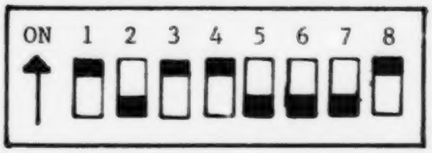
switch S1


ON
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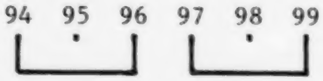
b) 16K EPROM (4-2732) (High Ram address 06FFF)

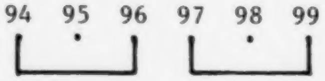

94
95
96
97
98
99

also Wire Wrap 127-128

switch S1

1	2	3	4	5	6	77	88
on	off	on	off	off	off	on	off

c) 32K EPROM (8-2732 with SBC 340 installed)
(High Ram address OFFFF)


94
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also jumper 127-128

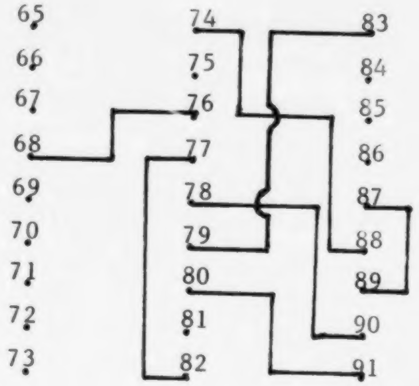
switch S1

1	2	3	4	5	6	7	8
on	off	off	off	off	off	off	off

THE 32K EPROM CONFIGURATION IS USED FOR OVEN CONTROL SYSTEMS.

Intel Microcomputer Configuration SBC 86/12 A (pg 3)	10/9/81 KLH

IV. Interrupts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Forth Interrupt	PIC Pin#	Interrupt Source	
8	81		
9	80	91	Timer 1 interrupt
10	79	83	Timer 0 Interrupt (MS Timer)
11	78	90	Transmit Buffer empty TX Intr (Type)
12	77	82	Receive Buffer empty RX Intr (Expect)
13	76	68	Int 5 from Multibus (Disk)
14	75		
15	74	88	Fail Safe Times interrupt

87-89 Non Maskable interrupt to ground

SBC 534 Communications Board

The only jumper which changes from the factory default settings is the base address. The required base address is HEX 80.

remove 118-125
add 120-125

All Dip headers should be in the first row.

i.e. sockets W1 to W4

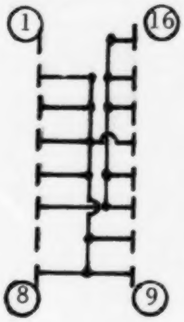
Intel Microcomputer Configuration | 10/13/81 | KLH

SBC 732 Analog I/O Board

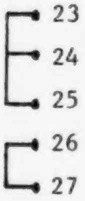
1. Base Address

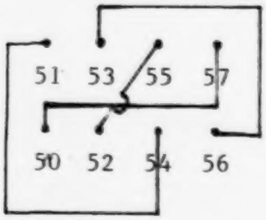
The base address is DC00 HEX

The 16 pin dip header is wired as follows



2. Multiplexers- Single Ended Input


23
24
25
26
27


51
53
55
57
50
52
54
56

Two Harris H181BA multiplexers must be installed in sockets A2, A5

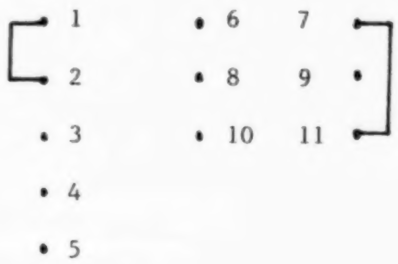
3. ADC straghtBinary Code 66-67 jumpered

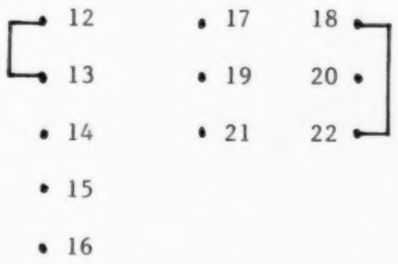
4. ADC Trigger remove 40-38
add 40-28

5. DAC Straight Binary Code 42-43

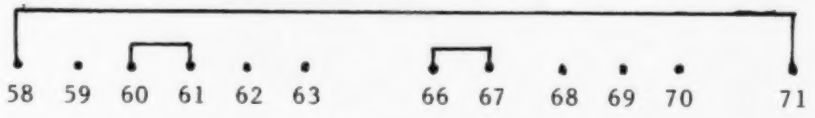
45-46

6. +10 V: Output


1
2
3
4
5
6
8
10
7
9
11


12
13
14
15
16
17
19
21
18
20
22

7. 410 VDC Input

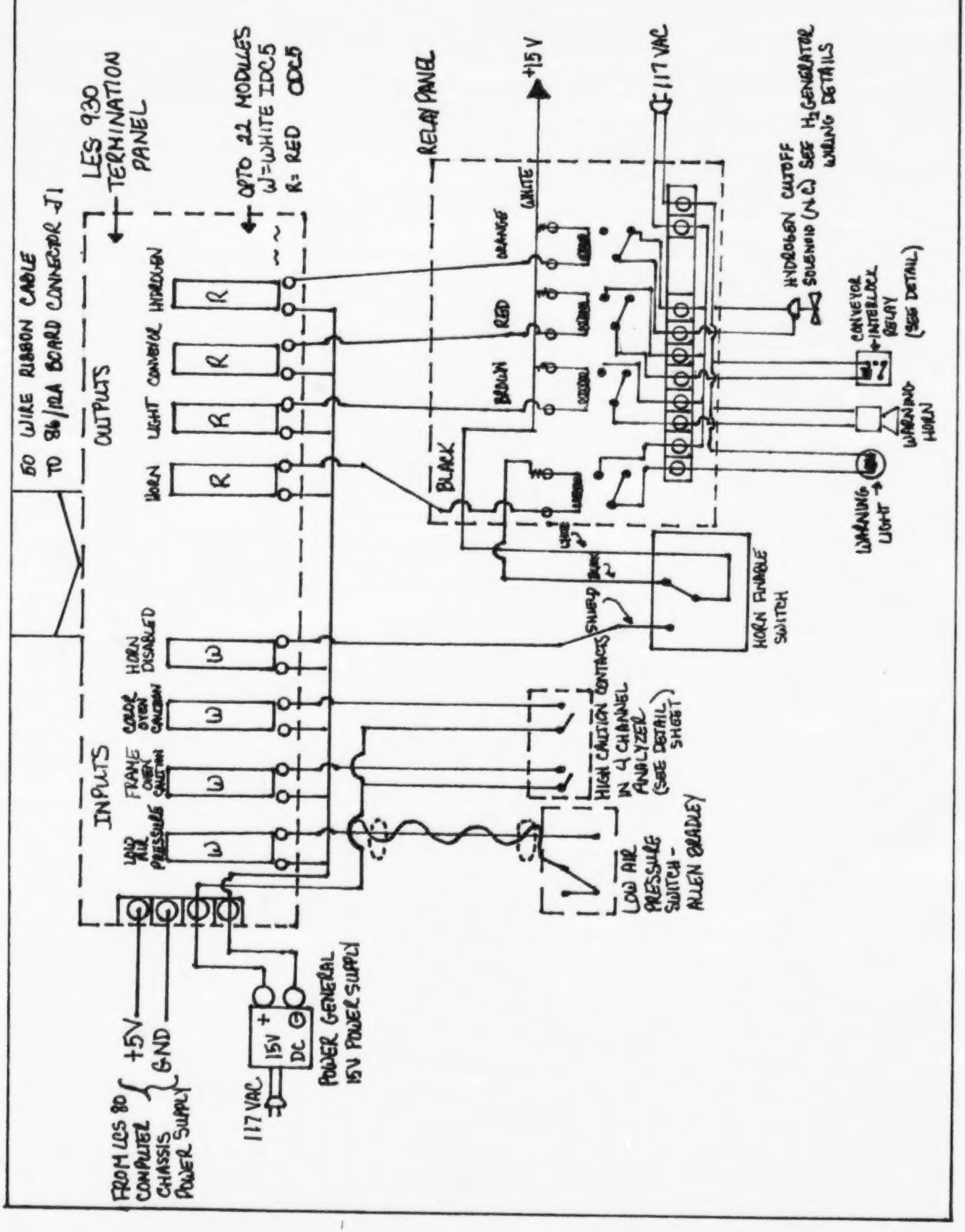

58
59
60
61
62
63
66
67
68
69
70
71

8. All other jumpers are factory default.

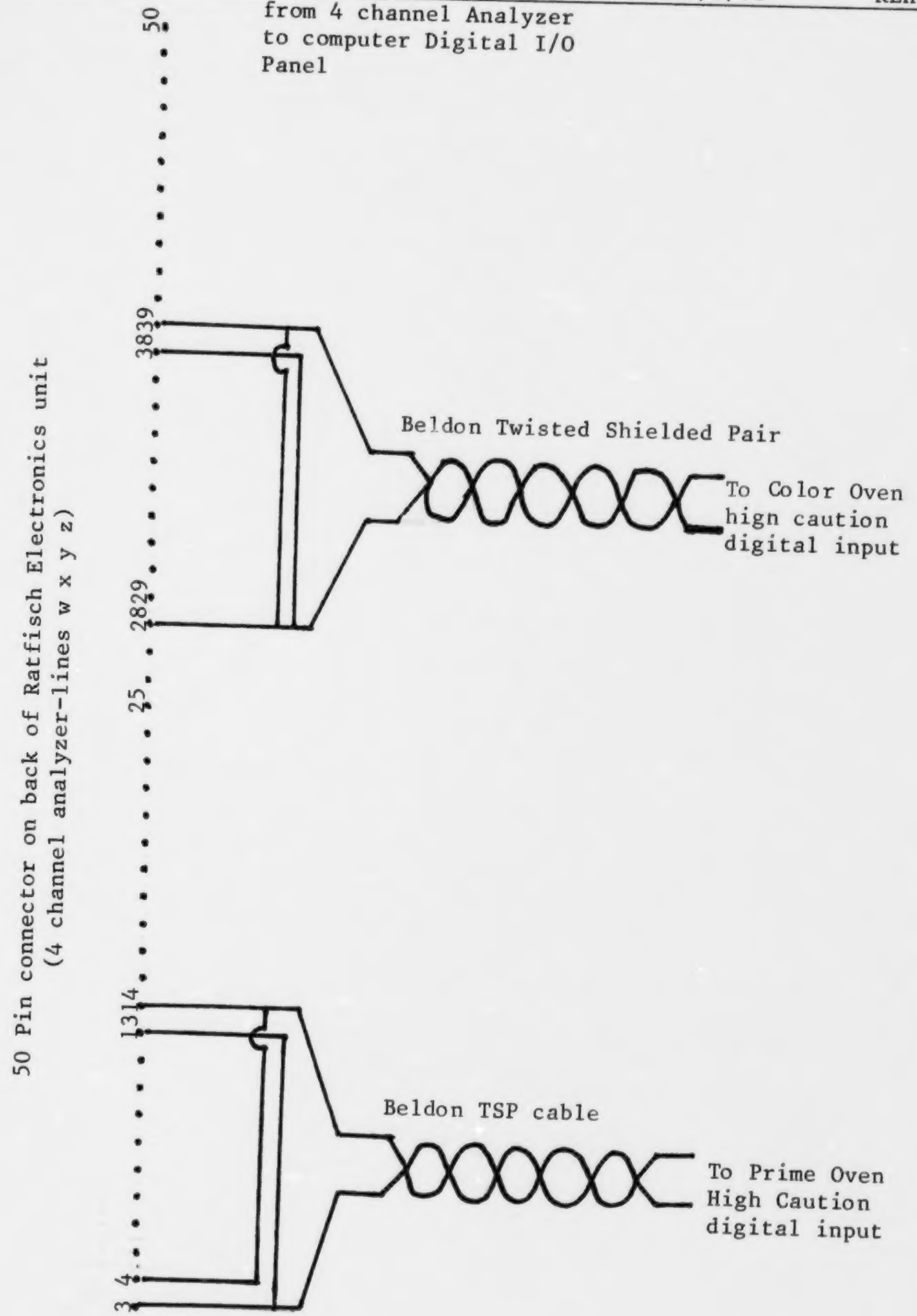
TCU-410 Clock Board

The TCU 410 requires no jumper changes. It can be used as it is received from the factory (Digital Pathways).

MACK TRUCKS CONTROLLER | DIGITAL I/O DETAILS | 9/21/81 KLH


50 WIRE RIBBON CABLE
TO 86/12A BOARD CONNECTOR J1
LES 930 TERMINATION PANEL
OPTO 22 MODULES
W=WHITE IDC5
R=RED ODC5
RELAY PANEL
+15V
117 VAC
OUTPUTS
HORN
LIGHT
LIGHT CONVEYOR
HYDROGEN
R
BLACK
BROWN
RED
ORANGE
WHITE
HYDROGEN CUTOFF SOLENOID (N.C.) SEE H2 GENERATOR WIRING DETAILS
CONVEYOR INTERLOCK RELAY (SEE DETAIL)
WARNING HORN
WARNING LIGHT
HORN ENABLE SWITCH
SHIELD
INPUTS
LOW AIR PRESSURE
FRAME OVEN CAUTION
CORE OVEN CAUTION
HORN DISABLED
W
HIGH CAUTION CONTACTS IN 4 CHANNEL ANALYZER (SEE DETAIL SHEET)
LOW AIR PRESSURE SWITCH - ALLEN BRADLEY
FROM LES 80 COMPUTER CHASSIS POWER SUPPLY
+5V
GND
117 VAC
15V DC
+
POWER GENERAL 15V POWER SUPPLY

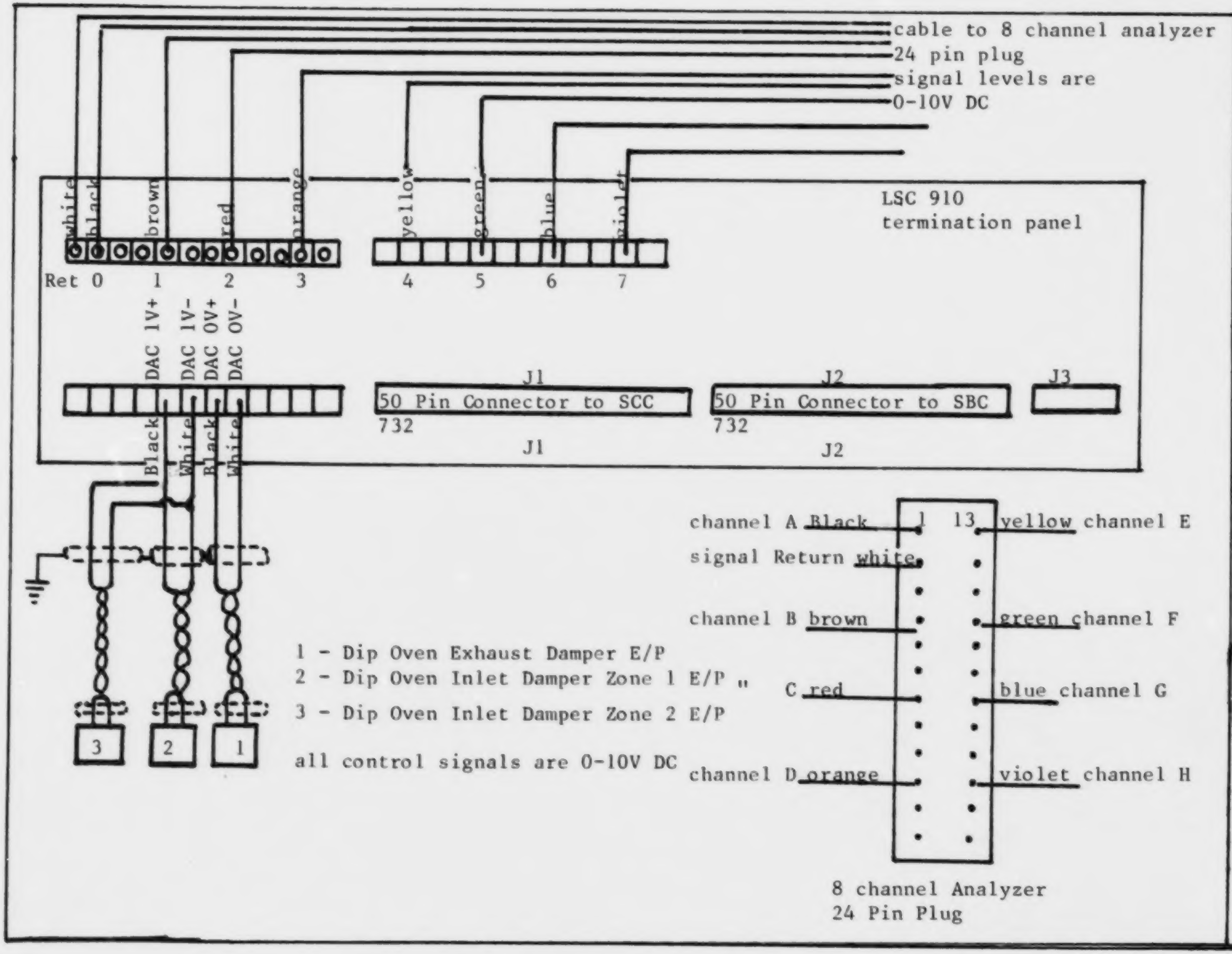
Mack Trucks Controller 50 Pin connector details 10/2/81 KLH
from 4 channel Analyzer
to computer Digital I/O
Panel


50 Pin connector on back of Ratfisch Electronics unit
(4 channel analyzer-lines w x y z)
50
38
39
28
29
25
13
14
1
3
4
Beldon Twisted Shielded Pair
To Color Oven
hign caution
digital input
Beldon TSP cable
To Prime Oven
High Caution
digital input

Mack Trucks Controller Analog I/O — 10/2/81 KLH

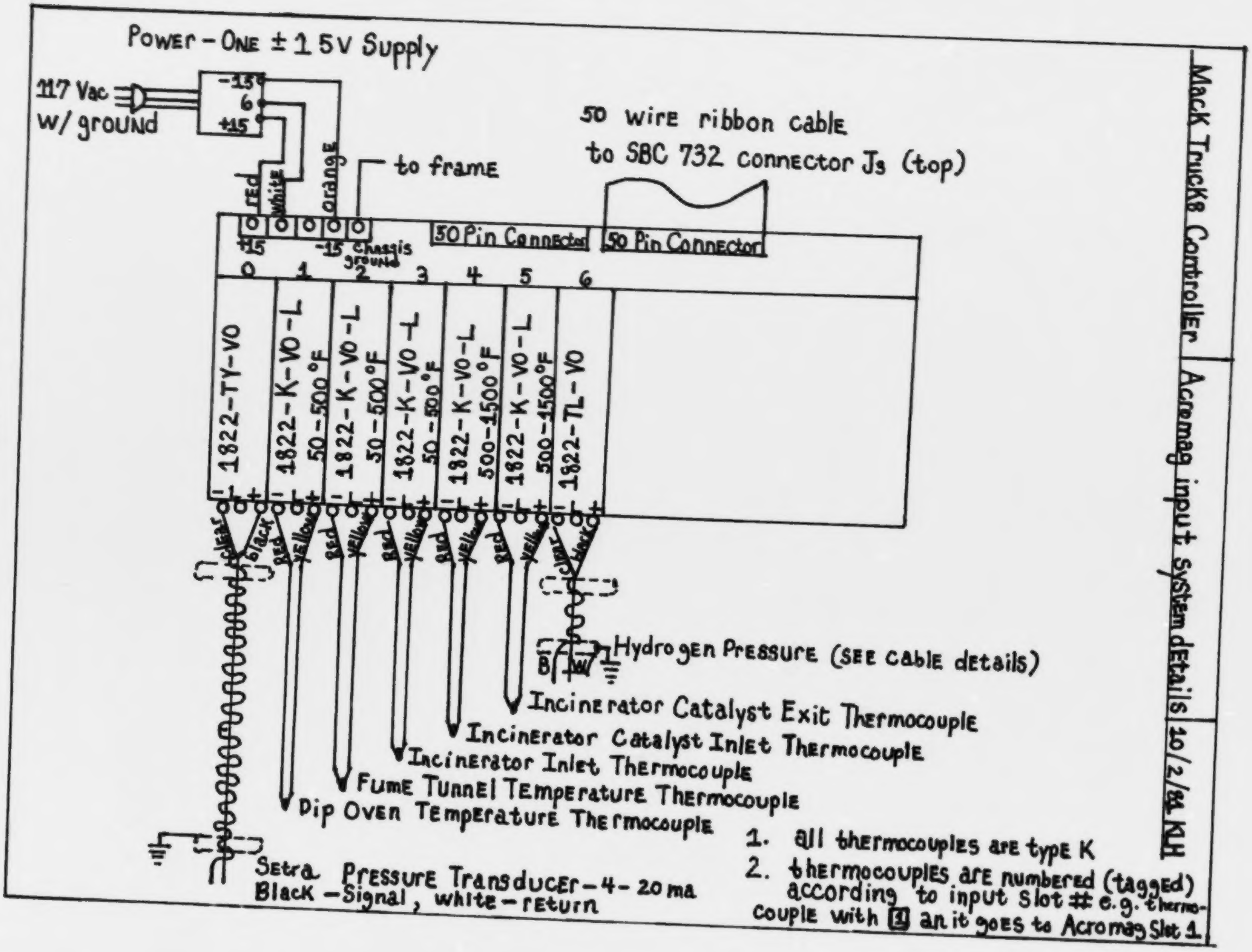
732 Board Input #	Process Variable	Sensor Output	Sensor Engineering Units Range	Sensor Tag on P&I diag.	Analyzer Channel
	LEL Sensors				
0	Main Control Point in Dip Oven	0-10V	0-50%	AITI A	A
1	Oven Exhaust (Backup Control)	↑	↑	B	B
2	Dip Oven Recirc Zone 1			C	C
3	Dip Oven Recirc Zone 2			D	D
4	Fume Tunnel			E	E
5	Incinerator Inlet			F	F
6	Incinerator Exhaust	↓	↓	G	G
7	Ambient	0-10V	0-50%	H	H
	Pressure				
16	Dip Oven Pressure	4-20ma	0-10"H_2O	PT-1	
	Temperature				
17	Dip Oven Exhaust Plenum	type K thermo-couple,mv	50-500°F	TT-2	
18	Fume Tunnel		50-500°F	TT-4	
19	Incinerator Inlet		50-500°F	TT-8	
20	Incinerator Catalyst Inlet	↓	500-1500°F	TT-6	
21	Incinerator Exhaust		500-1500°F	TT-7	
22	Pressure				
22	Hydrogen Pressure				70 to 90 mv/psig Acromag has 0-1.0v calibration
732 Board Output #	**Controlled Variable**	**732 Board Output Signal**	**Variable Range**	**Device Tag on P&I diag**	
0	Dip Oven Exhaust Damper	4-20ma	100-0% open		
1	Dip Oven Inlet Dampers (two dampers in series)	4-20ma	100-0% open		

Mack Trucks Controller	Les 910 panel details	10/1/81 KHL


cable to 8 channel analyzer
24 pin plug
signal levels are
0-10V DC
LSC 910
termination panel
white
black
brown
red
orange
yellow
green
blue
violet
Ret 0
1
2
3
4
5
6
7
DAC 1V+
DAC 1V-
DAC 0V+
DAC 0V-
Black
White
Black
White
J1
50 Pin Connector to SCC
732
J1
J2
50 Pin Connector to SBC
732
J2
J3
1
2
3
channel A Black
signal Return white
channel B brown
C red
channel D orange
1
13
yellow channel E
green channel F
blue channel G
violet channel H
8 channel Analyzer
24 Pin Plug

1 - Dip Oven Exhaust Damper E/P
2 - Dip Oven Inlet Damper Zone 1 E/P "
3 - Dip Oven Inlet Damper Zone 2 E/P

all control signals are 0-10V DC



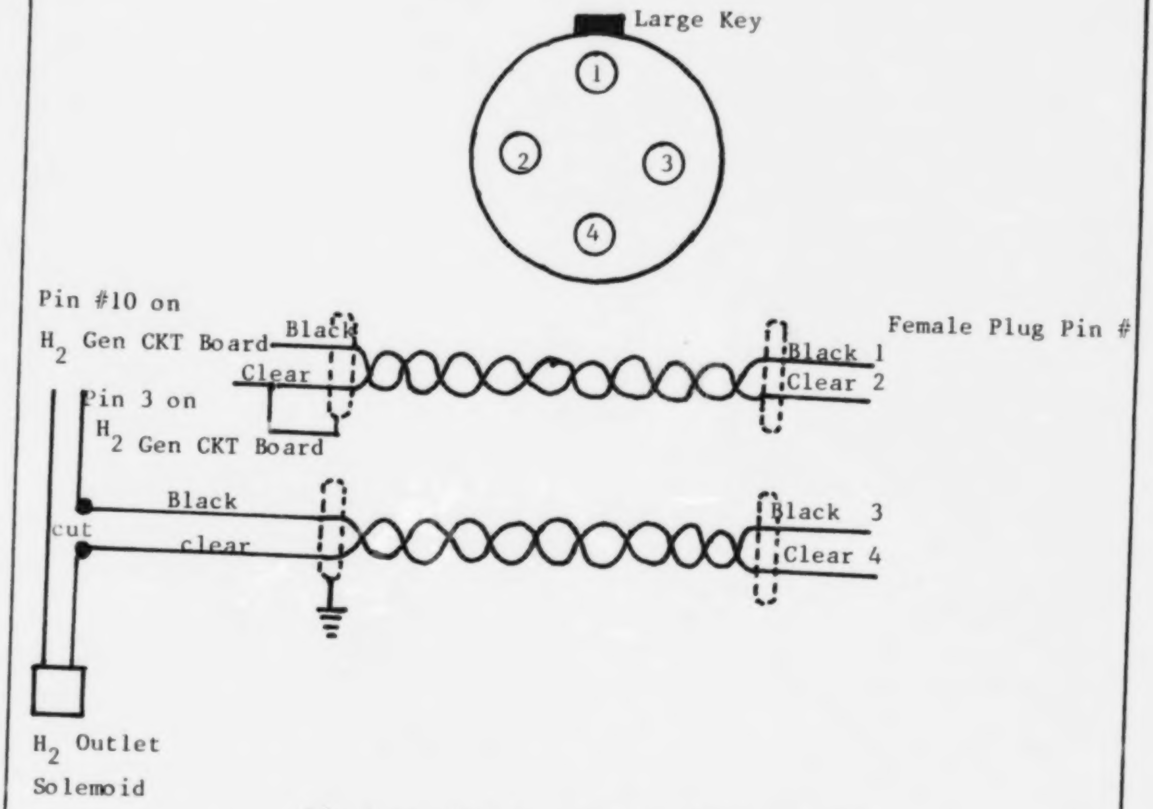
Mack Trucks Controller | Acromag input system details | 10/2/81 KLH

Power-One ± 15V Supply
117 Vac w/ ground
-15
6
+15
red
white
orange
to frame
+15
-15
Chassis ground
50 Pin Connector
50 Pin Connector
50 wire ribbon cable to SBC 732 connector J3 (top)
0
1
2
3
4
5
6
1822-TY-VO
1822-K-VO-L 50-500°F
1822-K-VO-L 50-500°F
1822-K-VO-L 50-500°F
1822-K-VO-L 500-1500°F
1822-K-VO-L 500-1500°F
1822-TL-VO
clear
black
Red
yellow
B
W
Hydrogen Pressure (SEE cable details)
Incinerator Catalyst Exit Thermocouple
Incinerator Catalyst Inlet Thermocouple
Incinerator Inlet Thermocouple
Fume Tunnel Temperature Thermocouple
Dip Oven Temperature Thermocouple
Setra Pressure Transducer - 4-20 ma
Black - Signal, white - return

1. all thermocouples are type K
2. thermocouples are numbered (tagged) according to input Slot # e.g. thermocouple with 1 an it goes to Acromag Slot 1

Mack Trucks Controlled	Hydrogen Generator to Computer Wiring Details	10/2/81 KHL

Female Plug on Top of Generator


Large Key
1
2
3
4
Pin #10 on
H2 Gen CKT Board
Black
Clear
Pin 3 on
H2 Gen CKT Board
Female Plug Pin #
Black 1
Clear 2
Black
cut
clear
Black 3
Clear 4
H2 Outlet
Solemoid

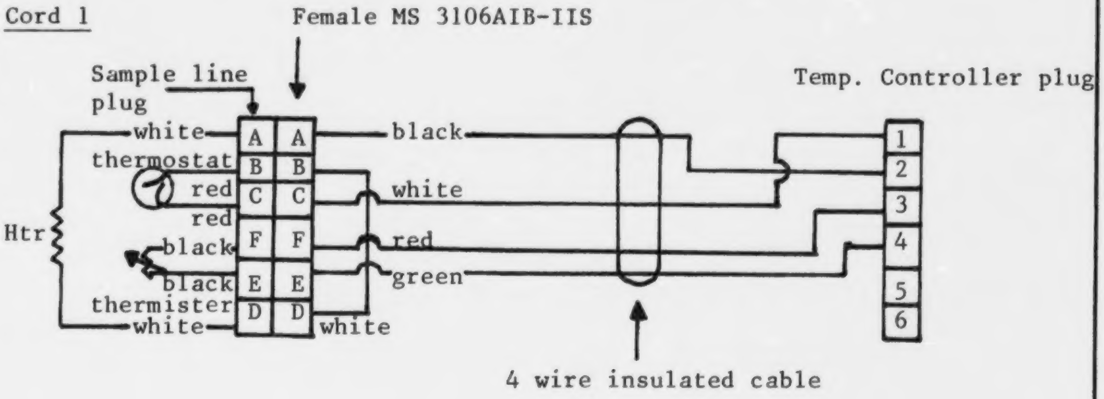
Pin 3 on circuit board is signal ground

Pin 10 should give a signal of about 7mv/psig

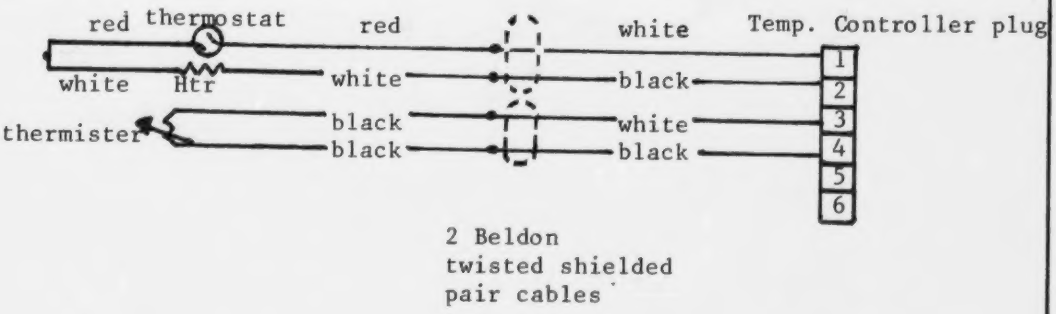
Mack Trucks Controller	Extension cords	9/22/81 KLH

Extend electric lines from two of the 4 channel analyzers heated sample lines to plug into the temperature control unit located in the B channel analyzer.

Cord 1


Female MS 3106AIB-IIS
Sample line plug
Temp. Controller plug
white
thermostat
red
red
Htr
black
black
thermister
white
A
B
C
F
E
D
A
B
C
F
E
D
black
white
red
green
white
1
2
3
4
5
6
4 wire insulated cable

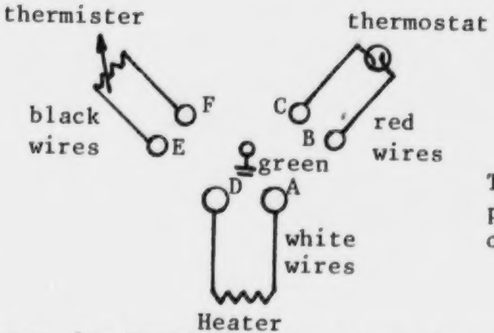
Cord 2


red
thermostat
red
white
Temp. Controller plug
white
Htr
white
black
thermister
black
black
white
black
1
2
3
4
5
6
2 Beldon twisted shielded pair cables

Mack Trucks Controller	New plugs on 8 channel Analyzers	9/21/81 KLH

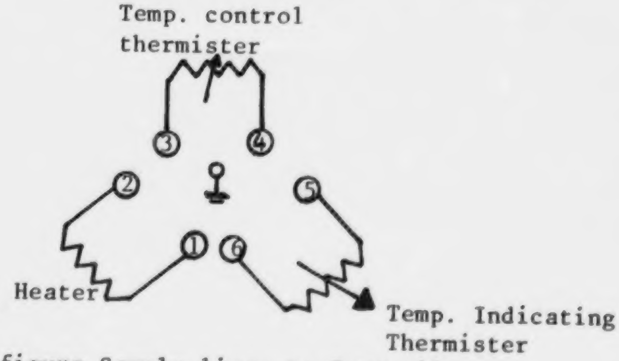
Heated sample line plugs

Original Pin layout of Technical Heaters plug

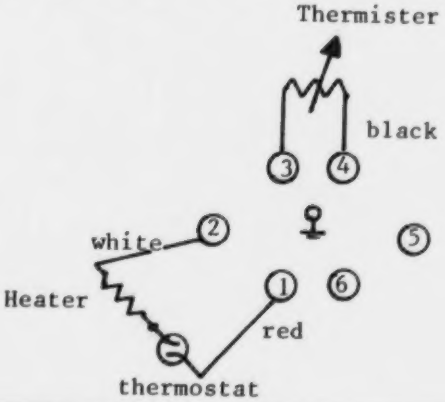

thermister
thermostat
black wires
F
E
C
B
red wires
green
D
A
white wires
Heater

Type J thermocouple protrucks from rear of plug

Required Pin layout for Ratfisch Temperature Controller


Temp. control thermister
3
4
2
5
1
6
Heater
Temp. Indicating Thermister

Wiring used to configure Sample lines to Controller


Thermister
black
3
4
white
2
5
Heater
1
6
red
thermostat

APPENDIX J

SOFTWARE LISTING FOR MICROCOMPUTER
AT
MACK TRUCKS, INC.

```
306 LIST
```

```
307 LIST
```

```
308 LIST

    0 LAST REVISED   22 APR 1982    11:31:43  MACK TRUCKS
    1
    2
    3
    4
    5
    6
    7
    8
    9
   10
   11
   12
   13
   14
   15
```

```
309 LIST

  0 ( CONTROLLER LOAD SCREEN)  ( EMPTY) ( 315 LOAD)
  1 ( SYSTEM STUFF)  316 317 THRU
  2 ( DATA ACQUISITION) 321 LOAD 324 LOAD
  3 ( 732 BOARD OUTPUT) 325 LOAD
  4 ( DIGITAL FILTER)  327 328 THRU
  5 ( BACKGROUND TASK -- DATA ACQUISITION) 329 LOAD
  6
  7 ( CONTROL LOOPS)
  8   ( 1LOOP LEL) 339 342 THRU
  9   ( 2LOOP PRESS) 345 348 THRU
 10   ( CONTROL WORDS) 350 LOAD
 11 ( BACKGROUND TASK-- CONTROL) 351 LOAD
 12
 13 ( ALARM CHECKING)   360 363 THRU  367 371 THRU
 14                     372 LOAD 373 LOAD
 15 310 LOAD


310 LIST

  0 ( CONTROLLER LOAD SCREEN II)
  1
  2 ( DESTRUCTION EFFICIENCY) 375 LOAD
  3 ( BACKGROUND TASK -- SAFETY ANALYSIS)  377 LOAD
  4
  5 ( OPERATOR INTERFACE)
  6   ( TERMINAL PRIMATIVES) 402  404 THRU
  7   ( CONVERSIONS) 420 LOAD 421 LOAD
  8   ( DISPLAY COLORS AND MESSAGES) 426 LOAD 427 LOAD
  9   ( SCREEN VARIABLES AND DRIVER) 432 LOAD 433 LOAD 435 LOAD
 10                                  438 LOAD 439 LOAD
 11   ( GENERAL SCREEN BUILDING WORDS) 441 443 THRU
 12
 13  311 LOAD
 14
 15


311 LIST

  0 ( CONTROLLER LOAD SCREEN III)
  1
  2 ( STATUS SCREEN TABLES) 447 455 THRU
  3 ( STATUS SCREEN WORDS) 459 461 THRU
  4 ( STATUS SCREEN MENU RESPONSE WORDS) 465 468 THRU
  5 ( MAIN MENU) 483 486 THRU
  6 ( CHANGE CONTROLLER CONSTANT SCREEN) 489 493 THRU 495 498 THRU
  7 ( TIMESET SCREEN) 104 LOAD 105 LOAD 501 505 THRU
  8 ( BULLDOG SCREEN) 405 LOAD  507 515 THRU
  9 ( INITIALIZE SCREEN ADDRESSES)  534 LOAD
 10 ( REPORT GENERATING)  537 541 THRU
 11  543 LOAD 544 LOAD  546 553 THRU
 12 ( BACKGROUND TASK -- REPORT GENERATING)  554 LOAD
 13 ( CONTROLLER STARTUP)  555 LOAD
 14
 15
```

```
315 LIST

( BACKGROUND TASK AREAS)
HEX

( DATA ACQUISITION TASK)  20 10 40 BACKGROUND 1AREA
( ALARM CHECKING TASK)    40 20 80 BACKGROUND 2AREA
( CONTROL TASK)           20 10 40 BACKGROUND 3AREA

DECIMAL

1AREA BUILD  2AREA BUILD   3AREA BUILD
```

```
316 LIST

( DIRECT BYTE ADDRESSING OF HARDWARE -- HC!)

CODE HC!           ( DATA  ADDR  ADDROFFSET <- TOS)
STI B              ( DISABLE INTERRUPTS)
DS POPS            ( LOAD DATA SEGMENT REGISTER WITH ADDROFFSET)
W POP              ( LOAD REGISTER W WITH ADDR)
0 POP              ( LOAD ACCUMULATOR WITH DATA)
0 W ) MOV B        ( MOVE CONTENS OF 0 TO ADDR POINTED TO BY W)
W IS SSG  W DS LSG  ( RESTORE SEGMENT REGISTER DS FROM IS)
STI  NEXT          ( ENABLE INTERRUPTS AND QUIT)
```

```
317 LIST

( DIRECT BYTE ADDRESSING OF HARDWARE -- HC@)

CODE HC@           ( ADDR  ADDROFFSET <- TOS)
STI B              ( DISABLE INTERRUPTS)
DS POPS            ( LOAD DATA SEGMENT REGISTER WITH ADDROFFSET)
W POP              ( LOAD W WITH ADDR)
0 0 SUB            ( CLEAR ACCUMULATOR)
W ) 0 MOV B        ( MOVE CONTENTS OF ADDR POINTED TO BY W INTO 0)
0 PUSH             ( PUSH CONTENTS OF REG. 0 ONTO THE STACK)
W IS SSG  W DS LSG  ( RESTORE SEGMENT REGISTER DS FROM IS)
STI  NEXT          ( ENABLE INTERRUPTS AND QUIT)
```

```
318 LIST

      0 ( PROM .")
      1
      2
      3
      4
      5 FORTH : ."  126 WORD DUP 1+ SWAP FORTH C@ OVER + SWAP
      6              DO I C@ HOST C, LOOP ; IMMEDIATE
      7
      8
      9
     10
     11
     12
     13
     14
     15
```

```
319 LIST
```

```
320 LIST
```

```
321 LIST

 ( DATA ACQUISITION VARIABLES)
HEX

DC00 CONSTANT BASEADDR ( HARDWARE ADDRESS OF ANALOG I/O BOARD)

DECIMAL

15 CONSTANT #DP  ( # OF DATA POINTS #DP)

VARIABLE ANDATA #DP 2* ALLOT ( ANALOG INPUT DATA )
```

```
322 LIST

   ( INPUT VARIABLE DESCRIPTIONS )
EXIT
( There are 32 analog input channels, the following are used)

(            VARIABLE          INPUT CHANNEL  FDATA + LOCATION   )

(   PRIMARY LEL SENSOR               0           0 )
(   OVEN EXHAUST LEL                 1           2 )
(   RECIRC ZONE 1 LEL                2           4 )
(   RECIRC ZONE 2 LEL                3           6 )
(   FUME TUNNEL                      4           8 )
(   INCINERATOR INLET LEL            5          10 )
(   INCINERATOR EXHAUST LEL          6          12 )
(   AMBIENT LEL                      7          14 )
```

```
323 LIST

   ( INPUT VARIABLE DESCRIPTIONS CONTINUED)
EXIT
(            VARIABLE          INPUT CHANNEL  FDATA +    )

(   DIP OVEN PRESSURE                16         16 )

(   DIP OVEN EXHAUST TEMPERATURE     17         18 )
(   FUME TUNNEL TEMPERATURE          18         20 )
(   INCINERATOR INLET TEMP           19         22 )
(   INC. CATALYST INLET TEMP         20         24 )
(   INCINERATOR EXHAUST TEMP         21         26 )

(   HYDROGEN PRESSURE                22         28 )
```

```
324 LIST

 ( 732 BOARD INPUT)
 ( INPUT RESOLUTION IS 12 BITS OR DECIMAL 0 TO 4095 RANGE)
 ( ENABLE loads the input number and enables conversion )
 ( READ gets 2 bytes  LLLL0000 then MMMMMMMM )
 ( A/D converts 12 bits to # between 0 and 4095)

 : X1ENABLE  BASEADDR 1+ 0  HC! 1 BASEADDR 0 HC! ;
 : READ  BASEADDR DUP 4 + 0 HC@ SWAP 5 + 0 HC@ ;
 : A/D  16 * SWAP 16 / + ;

 ( 0-7 LELS   8-14 TEMP,PRESS)
 : DATAIN   8 0 DO I X1ENABLE READ A/D ANDATA I 2* + ! LOOP
          15 8 DO I 8 + X1ENABLE READ A/D ANDATA I 2* + ! LOOP ;




325 LIST

 ( 732 BOARD OUTPUT)
 ( RANGE IS DECIMAL 0 TO 4095 i.e. 12 BITS)
 ( LEAST 4 SIGNIFICANT BITS OUTPUT FIRST -->  LLLL0000)
 ( MOST SIGNIFICANT 8 BITS NEXT            -->  MMMMMMMM )
 ( D/A SETS THE DECIMAL NUMBER UP FOR BYTE TRANSFER)


 : D/A  16 * DUP 0 256 M/ SWAP 240 AND ;
 : EXHDAMP  D/A   BASEADDR 8 + 0 HC!  BASEADDR 9 + 0 HC! ;
 : INDAMP   D/A   BASEADDR 10 + 0 HC! BASEADDR 11 + 0 HC! ;







326 LIST

 ( 732 BOARD CALIBRATION ROUTINES)
 : $$ ;
 : X8ENABLE  192 OR BASEADDR 1+ 0 HC! 1 BASEADDR 0 HC! ;
 : PGA  BEGIN 0 X1ENABLE 0 X8ENABLE DEVICE C@ INPUT 7 = END ;

 : ADCOFF   BEGIN  0 X1ENABLE READ A/D . CR DEVICE C@ INPUT
          500 MS 7 = END DECIMAL ;

 : SETDAC  D/A 2DUP BASEADDR 8 + 0 HC!  BASEADDR 9 + 0 HC!
    BASEADDR 10 + 0 HC! BASEADDR 11 + 0 HC! ;

 : OPEN  0 SETDAC ;
 : CLOSE   4095 SETDAC ;
 : HALF    4095 2 / SETDAC ;
 : SEE  X1ENABLE READ A/D . ;
```

```
327 LIST

      0 ( DIGITAL FILTER -- VARIABLES)
      1
      2 VARIABLE FDATA  #DP 2* ALLOT   ( FILTERED DATA)
      3
      4 ( INITIALIZE ARRAY)
      5 : 1INIT   #DP 2* ANDATA OVER ERASE FDATA SWAP ERASE ;
      6
      7
      8
      9
     10
     11
     12
     13
     14
     15
```

```
328 LIST

      0 ( DIGITAL FILTER)
      1
      2 ( SINGLE POLE FILTER)
      3 ( Y0 = G*X + B*Y1  )
      4
      5
      6 : FLTR   2* DUP DUP ANDATA + @ 27 M*    ( G * X)
      7          ROT FDATA + @ 73 M* D+ 50 0 D+ 100 M/      ( + B*Y1)
      8          SWAP FDATA + !  ;
      9
     10 #DP
     11 : ALLFILTER  ( ALL ANALOG DATA)  IN-LINE 0 DO I FLTR LOOP ;
     12
     13
     14
     15
```

```
329 LIST

      0 ( BACKGROUND TASK -- DATA ACQUISITION)
      1
      2 : ACQDATA  1AREA ACTIVATE BEGIN DATAIN ALLFILTER 75 MS 0 END ;
      3
      4 : 1KILL  1AREA ACTIVATE STOP ;
      5
      6
      7
      8
      9
     10
     11
     12
     13
     14
     15
```

```
339 LIST

  0 ( CONTROL LOOP 1   LEL -- VARIABLES)
  1
  2  VARIABLE 1SP  ( LEL SETPOINT AT 10%)
  3  VARIABLE 1KC  ( PROPORTIONAL CONSTANT)
  4          ( CARRY 1 DECIMAL PLACE WITH KC)
  5  VARIABLE 1TD  ( DERIVATIVE CONSTANT)
  6  VARIABLE 1TI  ( INTEGRAL CONSTANT)
  7  VARIABLE 1PI  ( PAST INTEGRAL)
  8  VARIABLE 1PR  ( PAST READING )
  9  VARIABLE 1PO  ( PAST OUTPUT  )
 10  VARIABLE 1dO  ( CHANGE FOR FEEDFORWARD ON PRESS)
 11
 12
 13 VARIABLE dt  ( CONTROL TIME INTERVAL)
 14 VARIABLE dCH ( MAX OUTPUT CHANGE PER CYCLE)
 15


340 LIST

  0   ( CONTROL LOOP 1 INITIALIZE VARIABLES)
  1
  2 : 2INIT    819  1SP !  4  1KC !  0 1TD !  6 1TI !
  3                0  1PI !  0  1PR !  0 1PO !  0 1dO !
  4                3   dt ! 100 dCH !    ;
  5
  6
  7
  8
  9
 10
 11
 12
 13
 14
 15


341 LIST

  0   ( CONTROL LOOP 1  LEL -- PID)
  1 : 1ERROR  1SP @ FDATA @ FDATA 2+ @ MAX FDATA 4 + @ MAX
  2           FDATA 6 + @ MAX - ;
  3 ( Look at all dip oven points and use max)
  4 : 1DERIV  1PR @ FDATA @ FDATA 2+ @ MAX  - 1TD @ dt @ */ ;
  5 : 1INTEG  1ERROR dt @ M* 1 1TI @ M*/ 4095 0 DMIN -4095 -1 DMAX
  6           DROP 1PI @ + DUP 1PI ! ;
  7 : 1MANIP  1ERROR 1INTEG + 1DERIV + 1KC @ M* 1 10 M*/ ;
  8 ( 1MANIP gives double precision output)
  9 : 1TRACK   1DERIV 1ERROR + 1KC @ 10 */ - 10 1KC @ */ 1PI ! ;
 10   ( TRACK NEEDS 0 OR 4095 ON STACK TO TRACK HI OR LO)
 11
 12 : 1CLAMP  ( DBLE PREC OUTPUT VAL--> CLAMPED SINGLE PREC VAL)
 13         2DUP 4095 0 D< IF  2DUP 0 0 D< IF 2DROP 0 DUP 1TRACK
 14                                          ELSE DROP THEN
 15                         ELSE 2DROP 4095 DUP 1TRACK THEN ;
```

```
342 LIST

     0   ( CONTROL LOOP 1  LEL -- SCALE OUTPUT)
     1
     2 : 1SLEW  DUP 1PO @ - DUP dCH @ > IF  SWAP DROP 0< IF
     3         dCH @ MINUS ELSE dCH @ THEN 1PO @ + ELSE DROP THEN
     4         DUP 1PO @ - 1dO ! DUP 1PO ! ;
     5
     6 : 1UPDT   FDATA @  FDATA 2+ @ MAX 1PR ! ;
     7 : 1LOOP  1MANIP 1CLAMP  1SLEW 1UPDT EXHDAMP ;
     8
     9
    10
    11
    12
    13
    14
    15


343 LIST

     0   ( CONTROL LOOP 1 COMMENTS)
     1 ( LEL and Damper position are proportional. i.e. an increase
     2   in the digital number to the damper results in an increased
     3   LEL §the damper closest.  The dampers are rectangular so
     4   the flow should be linear with position  )
     5 ( SLEW WORKS ONLY ON A CLOSING DAMPER, NO MOTION RESTRAINTS
     6  ARE PUT ON AN OPENING DAMPER)
     7
     8
     9
    10
    11
    12
    13
    14
    15


344 LIST
```

```
345 LIST

( CONTROL LOOP 2  PRESS - VARIABLES)

VARIABLE 2SP  ( OVEN PRESSURE -2.0 in. H2O)
VARIABLE 2KC  ( PROPORTIONAL CONSTANT)
  ( CARRY 1 DECIMAL PLACE WITH KC)
VARIABLE 2TD  ( DERIVATIVE CONSTANT)
VARIABLE 2TI  ( INTEGRAL CONSTANT)
VARIABLE 2PI  ( PAST INTEGRAL)
VARIABLE 2PR  ( PAST READING )
VARIABLE 2PO  ( PAST OUTPUT  )
```

```
346 LIST

  ( CONTROLL LOOP 2 -- INIT VARIABLES )

: 3INIT    819 2SP !    8  2KC !   0 2TD !  6  2TI !
                0 2PI !    0  2PR !   0 2PO !             ;
```

```
347 LIST

  ( CONTROL LOOP 2  PRESS -- PID)
: 2ERROR  2SP @   FDATA 16 + @ - ;
: 2DERIV  2PR @ FDATA 16 + @ - 2TD @ dt @ */ ;
: 2INTEG  2ERROR dt @ M* 1 2TI @ M*/ 4095 0 DMIN -4095 -1 DMAX
          DROP 2PI @ + DUP 2PI ! ;
: 2MANIP  2ERROR 2INTEG + 2DERIV + 2KC @ M* 1 10 M*/ ;
( MANIP gives double precision output)
: FEEDFORWARD  1dO @  2/ M+ ;
( DBL PREC > DBL PREC)
: 2TRACK   2DERIV 2ERROR + 2KC @ 10 */ - 10 2KC @ */ 2PI ! ;
  ( TRACK NEEDS 0 OR 4095 ON STACK TO TRACK HI OR LO)

: 2CLAMP  ( DBLE PREC OUTPUT VAL--> CLAMPED SINGLE PREC VAL)
        2DUP 4095 0 D< IF  2DUP 0 0 D< IF 2DROP 0 DUP 2TRACK
                                     ELSE DROP THEN
                        ELSE 2DROP 4095 DUP 2TRACK THEN ;
```

```
351 LIST

( BACKGROUND TASK -- CONTROL )

: PROCCTRL   3AREA ACTIVATE BEGIN 1LOOP 2LOOP
             dt @ 1000 * 10 - MS 0 END ;


: 3KILL  3AREA ACTIVATE 0 INDAMP 0 EXHDAMP STOP ;
```

```
352 LIST
```

```
353 LIST
```

```
360 LIST

( ALARM CHECKING VARIABLES)

19 CONSTANT #ALARMS

VARIABLE ALARMS #ALARMS 2* ALLOT

#ALARMS 2*
: 4INIT  ALARMS IN-LINE ERASE ;
```

```
361 LIST

( ALARM TABLE FOR ANALOG ALARM VALUES)
CREATE ALARMTABLE 14 ,
( alarm                data addr     limit   hi-low 0=hi)
( PRIMARY LEL HA  )    FDATA     ,  4085 , 0 , ALARMS      ,
( OVEN EXH LEL HA )    FDATA 2 + ,  4085 , 0 , ALARMS 2 +  ,
( RECIRC ZONE 1 HA)    FDATA 4 + ,  4085 , 0 , ALARMS 4 +  ,
( RECIRC ZONE 2 HA)    FDATA 6 + ,  4085 , 0 , ALARMS 6 +  ,

( PRIMARY LEL HC  )    FDATA     ,  3685 , 0 , ALARMS 8 +  ,
( OVEN EXH LEL HC )    FDATA 2 + ,  3685 , 0 , ALARMS 10 + ,
( FUME TUNNEL LEL HC)  FDATA 8 + ,  3685 , 0 , ALARMS 12 + ,

( HIGH ALARM AT 50% LEL , HIGH CAUTION AT 45% LEL)
```

```
362 LIST

    ( ALARM TABLE FOR ANALOG ALARM VALUES CONTINUED)

( LEL SENSOR FAILURES)

( PRIMARY SENSOR)  FDATA      ,   6 , 1 , ALARMS 14 + ,
( OVEN EXHAUST  )  FDATA 2 +  ,   6 , 1 , ALARMS 16 + ,
( RECIRC ZONE 1 )  FDATA 4 +  ,   6 , 1 , ALARMS 18 + ,
( RECIRC ZONE 2 )  FDATA 6 +  ,   6 , 1 , ALARMS 20 + ,
( FUME TUNNEL   )  FDATA 8 +  ,   6 , 1 , ALARMS 22 + ,
( INCIN INLET   )  FDATA 10 + ,   6 , 1 , ALARMS 24 + ,

( LOW HYDROGEN PRESS)  FDATA 28 + ,  4000 , 1 , ALARMS 28 + ,
363 LIST

      0 ( ANALOG INPUT RANGE CHECKING WORDS)
      1 ( SEE D-CHARTS IN NOTEBOOK)
      2
      3 : ?OFF  DUP 6 + @ @ IF DUP @ @ OVER 2 + @ - ABS 3 >
      4          IF 0 SWAP 6 + @ ! ELSE DROP THEN ELSE DROP THEN ;
      5
      6 ALARMTABLE DUP @ 8 * OVER + SWAP 2 + SWAP
      7
      8 : RNGEALARMS  IN-LINE  IN-LINE DO I @ @    ( DATA)
      9        I 2 + @ > I 4 + @ IF NOT THEN      ( LIMIT , HILO)
     10        IF 1 I 6 + @ ! ELSE I ?OFF THEN 8 +LOOP ;
     11
     12
     13
     14
     15

364 LIST




365 LIST
```

```
366 LIST

( DIGITAL ALARM POINTS)  EXIT
( INPUTS)
( VARIABLE              ALARM #   PORT C8 BIT   NORMAL STATUS)
( LOW AIR PRESSURE       16          0                0      )
( PRIME OVEN HIGH CAUT   17          1                1      )
( COLOR OVEN HIGH CAUT   18          2                1      )
( ALARM HORN DISABLED    19          3                0      )

( OUTPUTS)
( VARIABLE          PORT CA BIT         NORMAL STATUS)
( ALARM HORN             0                 0 )
( ALARM LIGHT            1                 0 )
( CONVEYOR INTERLOCK     2                 0 )
( HYDROGEN GENERATOR     3                 0 )



367 LIST

( DIGITAL ALARM CHECKING)
 ( READ 8 INPUTS FROM HEX PORT C8)

18 17 16 15
HEX
: DALARM  C8 INPUT OF AND
     DUP 1 AND ALARMS IN-LINE 2* + !
     DUP 2 AND NOT ALARMS IN-LINE 2* + !
     DUP 4 AND NOT ALARMS IN-LINE 2* + !
         8 AND ALARMS IN-LINE 2* + ! ;

DECIMAL



368 LIST

( COMPLETE CHECK FOR ALARMS)

#ALARMS

: ?ALARM  RNGEALARMS DALARM 0 IN-LINE 0 DO
          ALARMS I 2* + @ + LOOP ;
( LEAVES THE NUMBER OF ALARMS ON THE STACK)
```

```
369 LIST

  0 ( ALARM HANDLING VARIABLES)
  1
  2 VARIABLE WRDOUT
  3 VARIABLE ENABLEHORN
  4 VARIABLE AUTOCTRL
  5 VARIABLE TIMEOUT
  6 VARIABLE SWITCH
  7
  8 VARIABLE ALOK 8 ALLOT
  9 VARIABLE LSTALRMS  #ALARMS 2* ALLOT
 10
 11 : 5INIT  0 AUTOCTRL !  0 WRDOUT !  0 ENABLEHORN !
 12          LSTALRMS #ALARMS 2* ERASE  ;
 13
 14
 15


370 LIST

  0 ( ALARMING BASIC FUNCTIONS)
  1
  2 : LITEON   2  WRDOUT @ OR WRDOUT ! ;
  3 : HORNON  ENABLEHORN @ IF 1  WRDOUT @ OR WRDOUT ! THEN ;
  4 : DRIVEOFF 4  WRDOUT @ OR WRDOUT ! ;
  5 : H2OFF   ENABLEHORN @ IF 8  WRDOUT @ OR WRDOUT ! THEN ;
  6 : MANUAL   0 AUTOCTRL ! ODAMP 3AREA ACTIVATE STOP ;
  7
  8
  9
 10
 11
 12
 13
 14
 15


371 LIST

  0 ( ALARMING BASIC FUNCTIONS)
  1
  2 : ?LITEOFF   SWITCH @ IF MINUTE TIMEOUT @ = IF 0 SWITCH !
  3             ELSE LITEON THEN THEN ;
  4
  5 : ?LITEON   LSTALRMS #ALARMS 2* ALARMS -TEXT IF
  6            LITEON 1 SWITCH ! MINUTE 5 + 60 MOD TIMEOUT !
  7            ALARMS LSTALRMS #ALARMS 2* MOVE
  8            ELSE ?LITEOFF  THEN ;
  9
 10
 11
 12
 13
 14
 15
```

```
372 LIST

 ( ALARMING ACTIONS)

 : ?H2OFF  ALARMS 28 + @ ALARMS 30 + @ OR IF H2OFF THEN ;

 : ?DRIVEOFF  4 0 DO I 2* ALARMS + @
                IF DRIVEOFF LEAVE THEN LOOP ;

 : ?ODAMP  ALARMS 8 + @ ALARMS 10 + @ OR IF ODAMP THEN ;

 : ?MANUAL  WRDOUT @ 8 AND   ( H2OFF)
            WRDOUT @ 4 AND  OR  ( OR DRIVEOFF)
            ALARMS 14 + @ ALARMS 16 + @ AND OR ( 2 SENSOR FAIL)
            IF MANUAL HORNON THEN ;




373 LIST

 ( FINIAL ALARM HANDLER)
 : ?OK
 ALARMS     @ ALARMS  8 + @ OR ALARMS 14 + @ OR NOT ALOK      !
 ALARMS 2 + @ ALARMS 10 + @ OR ALARMS 16 + @ OR NOT ALOK 2 + !
 ALARMS 4 + @                  ALARMS 18 + @ OR NOT ALOK 4 + !
 ALARMS 6 + @                  ALARMS 20 + @ OR NOT ALOK 6 + !
              ALARMS 12 + @    ALARMS 22 + @ OR NOT ALOK 8 + ! ;
HEX
 : SAFETY   WRDOUT @ 1 AND 0= IF 0 WRDOUT !  ?ALARM  IF
            ?LITEON ?H2OFF ?DRIVEOFF ?ODAMP ?MANUAL
            THEN WRDOUT @ CA OUTPUT  ?OK THEN ;
   ( If the horn is on, leave all outputs as they are)
DECIMAL




374 LIST
```

```
375 LIST

( DESTRUCTION EFFICIENCY CALCULATION)
( Incinerator inlet and outlet scales are the same)

VARIABLE  %DE

: 6INIT  0 %DE ! ;

: CALCDE    FDATA 10 + @ DUP 6 < IF
            DROP 999 ELSE
            FDATA 12 + @ 2DUP < IF
              2DROP 0 ELSE
              OVER SWAP - 1000 ROT */ THEN
            THEN %DE ! ;

( %DE will have one decimal place i.e. 900 -> 90.0 % D.E. )
```

```
376 LIST
```

```
377 LIST

( BACKGROUND TASK -- SAFETY ANALYSIS)

: ALARMER  2AREA ACTIVATE BEGIN SAFETY CALCDE 775 MS 0 END ;


: 2KILL 2AREA ACTIVATE STOP ;
```

```
402 LIST

   0 ( ISC COLOR TERMINAL - COLOR SETTING PRIMATIVES)
   1
   2 MSG BLCK 1 C, 16 C,
   3 MSG RED  1 C, 17 C,
   4 MSG GREEN 1 C, 18 C,
   5 MSG YELLOW 1 C, 19 C,
   6 MSG BLUE  1 C, 20 C,
   7 MSG MAGENTA 1 C, 21 C,
   8 MSG  CYAN  1 C, 22 C,
   9 MSG  WHITE  1 C, 23 C,
  10
  11 MSG SFG 1 C, 29 C, ( SET FOREGROUND)
  12 MSG SBG 1 C, 30 C, ( SET BACKGROUND)
  13
  14
  15


403 LIST

   0 ( ISC COLOR TERMINAL - WRITING PRIMITIVES)
   1
   2 MSG SDH 1 C, 14 C, ( SET DOUBLE HEIGHT)
   3 MSG SSH 1 C, 15 C, ( SET SINGLE HEIGHT)
   4 MSG SBL 1 C, 31 C, ( SET BLINK ON)
   5 MSG CBL 1 C, 15 C, ( CANCEL BLINK AND DOUBLE HEIGHT)
   6
   7 MSG VERTICAL 2 C, 27 C, 10 C, ( WRITE VERTICALLY)
   8 MSG NORMAL 2 C, 27 C, 11 C, ( WRITE HORIZONTALLY)
   9 MSG RTOL   2 C, 27 C, 84 C, ( WRITE RIGHT TO LEFT)
  10 MSG ROLL   2 C, 27 C, 75 C, ( ROLL AROUND)
  11
  12
  13
  14
  15


404 LIST

   0 ( ISC COLOR TERMINAL - CURSER MOVES)
   1
   2 MSG LEFT 1 C, 26 C,
   3 MSG RIGHT 1 C, 25 C,
   4 MSG UP 1 C, 28 C,
   5 MSG DOWN 1 C, 10 C,
   6 MSG EL 1 C, 11 C, ( ERASE LINE)
   7
   8 MSG HOME 1 C, 8 C, ( PUT CURSER AT 0 0 )
   9 MSG CXYSET 1 C, 3 C, ( CURSER SENT TO NEXT TWO CHARS EMITED)
  10
  11 : GOTOXY  SWAP CXYSET EMIT EMIT ;
  12
  13 ( CHAR SCREEN IS 0 TO 47 LINES 0 TO 79 CHARACTERS)
  14 ( CHAR ORIGIN UPPER LEFT)
  15 ( PUTTING CURSER AT POSITION 80 MAKES IT DISAPPEAR)
```

```
405 LIST

( ISC COLOR TERMINAL - GRAPHICS)

( GRAPHICS MODE)
MSG GRAPH 1 C, 2 C,       ( ENTER GRAPHICS)
MSG ALPHA 1 C, 255 C,     ( EXIT GRAPHICS)
MSG VECTOR 1 C, 242 C,
MSG POINT  1 C, 253 C,

( GRAPHICS SCREEN IS 0 TO 159 WIDE BY 0 TO 191 HIGH)
( GRAPH ORIGIN LOWER LEFT )
```

```
406 LIST
```

```
407 LIST
```

```
420 LIST

( 12 BIT TO ENGINEERING UNITS CONVERSIONS)
: OSUPTYP  2DUP > IF 1+ 0 SWAP DO 88 EMIT LOOP 2DROP
           ELSE OVER - SPACES TYPE THEN ;
: >LEL    500 4095 */ 5 + 10 /  0 <# #S #> 4 OSUPTYP ."  %" ;
: >LELLOW 500 4095 */ 5 + 10 / 0 <# #S #> 4 OSUPTYP ."  %" ;
: >1PRESS  100 4095 */ ABS 45 EMIT 0 <# # 46 HOLD # #> TYPE ;
: >PRESS   >1PRESS   ."  in H2O" ;
: >2PRESS  >1PRESS 2 SPACES ;
: >TEMP   450 4095 */ 50 + 0 <# #S #> 4 OSUPTYP  ."  F " ;
: >TEMPHIGH  1000 4095 */ 500 + 0 <# #S #> 4 OSUPTYP  ."  F " ;
: >%DE    0 <# # 46 HOLD #S #> 5 OSUPTYP ."  %" ;
: >DP%  4095 SWAP - 1000 4095 */ 5 + 10 / 0 <# #S #> 5
      OSUPTYP ."  %" ;
: >PLAIN  0 <# #S #> 4 OSUPTYP ."   " ;
```

```
421 LIST

( ENGINEERING UNITS TO 12 BIT CONVERSIONS)

: LEL>   4095 50 */ ;

: PRESS>    4095 10 */ ;
: TEMP>  50 - 4095 450 */ ;
: TEMPHIGH>  500 - 4095 1000 */ ;
```

```
422 LIST

( UNITS CONVERSION DOCUMENTATION)


( VARIABLE      RANGE      UNITS     #DEC-PLCE    COMP-RANGE
   LEL         0 - 50      %LEL          1          0 - 500
   LELLOW      0 - 25      %LEL          1          0 - 250
   PRESS       0 - -10     in. H2O       1          0 - -100
  TEMP        50 - 500      Deg. F       0         50 - 500
 TEMPHIGH    500 - 1500     Deg. F       0        500 - 1500)

( ALL INTERNAL REPRESENTATIONS ARE 0 TO 4095 , SO -10.0
  PRESSURE IS 4095)
```

```
426 LIST

   0 ( COLOR DISPLAY MODES)
   1 : STD  CBL SFG WHITE    SBG BLCK ;
   2 : NORM CBL SFG WHITE    SBG BLUE ;
   3 : CAUT CBL SFG BLCK     SBG YELLOW ;
   4 : ALAR SBL SFG WHITE    SBG RED    ;
   5 : NONE CBL SFG WHITE     SBG WHITE   ;
   6 : TITL SDH SFG CYAN     SBG BLCK   ;
   7 : LABL CBL SFG CYAN     SBG BLCK   ;
   8 : INVF CBL SFG BLUE     SBG WHITE  ;
   9
  10
  11
  12
  13
  14
  15


427 LIST

   0 ( STANDARD  MESSAGES)
   1 : 1MSG  NORM  ."  NORMAL " ;
   2 : 2MSG  CAUT  ." CAUTION "  ;
   3 : 3MSG  ALAR  ."  ALARM  "  ;
   4 : 4MSG  CAUT  ." FAILURE "  ;
   5 : 5MSG  ALAR  ." MONITOR " ;
   6 : 6MSG  NORM  ."   AUTO  " ;
   7 : 7MSG  CAUT  ."   HIGH  " ;
   8 : 8MSG  CAUT  ."   LOW   " ;
   9 : 9MSG  ALAR  ."   OFF   " ;
  10 : 0MSG  NORM  ."   ON    " ;
  11 : NULL ;
  12 : BAD  20 43 GOTOXY  ALAR ."  < INVALID RESPONSE > "
  13          20 43 GOTOXY 4 0 DO 7 EMIT 500 MS LOOP STD EL ;
  14
  15

428 LIST
```

```
432 LIST

 ( OPERATOR INTERFACE VARIABLES)
  VARIABLE DISPLAYS 16 ALLOT

  VARIABLE  'CONTROL-PARAMS
  VARIABLE  'CON
  VARIABLE  'COFF
  VARIABLE  'HORNOFF
  VARIABLE  'REPORT
  VARIABLE  'MENU
  VARIABLE  'STATUS-SCREEN
  VARIABLE  'SETCLOCK
  VARIABLE  'BULLDOG

  VARIABLE  ?REFRESH
  VARIABLE  ?REPORT
  VARIABLE  PRIOR


433 LIST

 ( OPERATOR INTERFACE VARIABLES INITIALIZATION)

 : 8INIT
        'CONTROL-PARAMS    DISPLAYS      !    ( 0)
        'CON              DISPLAYS  2 + !    ( 1)
        'COFF             DISPLAYS  4 + !    ( 2)
        'HORNOFF          DISPLAYS  6 + !    ( 3)
        'MENU             DISPLAYS  8 + !    ( 4)
        'REPORT           DISPLAYS 10 + !    ( 5)
        'STATUS-SCREEN    DISPLAYS 12 + !    ( 6)
        'SETCLOCK         DISPLAYS 14 + !    ( 7)
        'BULLDOG          DISPLAYS 16 + !    ( 8)
 0 ?REPORT !      1 ?REFRESH !  ;

 ( 1 => CURRENT ACTION MESSES UP DISPLAY SO NEXT SCREEN
    MUST START WITH STATIC PART)


434 LIST
```

```
435 LIST

( OPERATOR INTERFACE SCREEN DRIVER)

: DRIVER  BEGIN 2* DISPLAYS + @ @ EXECUTE 0 END ;

( Requires the display number of the screen to be executed
  on the stack.  Each screen when it is finished must leave
  the number of the next screen on the stack)
```

```
436 LIST
```

```
437 LIST
```

```
438 LIST

  0 ( SCREEN BUILDING VARIABLES)
  1
  2 VARIABLE  'DISPVALUE
  3 VARIABLE  'CHNGVALUE
  4 VARIABLE  'DISPDIGITAL
  5 VARIABLE  'WORDSSTATIC
  6 VARIABLE  'TABLESTATIC
  7
  8
  9
 10
 11
 12
 13
 14
 15


439 LIST

  0 ( OTHER SCREEN VARIABLES)
  1
  2 VARIABLE  REPORT-HR
  3 VARIABLE  BEGIN-HR
  4
  5
  6
  7
  8
  9
 10
 11
 12
 13
 14
 15

440 LIST
```

```
441 LIST

( STATIC DISPLAY FUNCTION)

: POSITION  CXYSET DUP @ EMIT 2+ @ EMIT ;
  ( ADDR OF X COORD ON STACK, Y COORD IN NEXT ADDR)

: STAT    'TABLESTATIC @ DUP @ 10 * OVER + SWAP 2 + DO
           I POSITION
           I 4 + @ EXECUTE  ( SET COLOR)
           'WORDSSTATIC @ I 6 + @ + I 8 + @ TYPE 10 +LOOP
           STD ( SET COLOR TO B/W) ;

( Displays words from 2 tables. 'TABLESTATIC contains address of
  table 1 which has # of entries then XCOORD , YCOORD , ADDR
  OF COLOR SETING WORD , STARTING POS IN WORD TABLE, # LETTERS
 for each word to be typed)
```

```
442 LIST

( VALUE DISPLAY FUNCTION)

: ANALO     NORM ( print values white on blue background)
           'DISPVALUE @  DUP @ 8 * OVER + SWAP 2 + DO
           I POSITION
           I 4 + @  @  ( GET DATA)
           I 6 + @ EXECUTE ( CONVERT AND PRINT)  8 +LOOP
           STD  ;


( Data table contains # ENTRIES , then
  XCOORD , YCOORD , ADDR OF DATA , ADDR OF PRINTING ROUTINE
 for each value)
```

```
443 LIST

( DIGITAL DISPLAY FUNCTION)
: DIGITAL  'DISPDIGITAL @  DUP @ 10 * OVER + SWAP 2 + DO
           CXYSET I @ EMIT I 2+ @ EMIT
           I 4 + @ @ ( GET DATA)
           IF  I 6 + @  ELSE I 8 + @ THEN EXECUTE
           10 +LOOP  STD ;


( Data table contains # ENTRIES , then
  X , Y , ADDR OF DATA , ADDR OF TRUE MSSG PRINTER , ADDR OF
  FALSE MSSG PRINTER for each entry )
```

```
447 LIST

  0 ( STATUS SCREEN STATIC WORDS)
  1 CREATE 1WORDS
  2 ." SMALL PARTS LINE STATUSLEL SENSORS          LEL    STATUSDIP"
  3 ."  OVEN CONDITIONSDIP OVEN CONTROL POINTDIP OVEN EXHAUSTDIP O"
  4 ." VEN RECIRC ZONE 1DIP OVEN RECIRC ZONE 2INCINERATOR INLETINC"
  5 ." INERATOR EXHAUSTAUXILIARY AMBIENTINSTRUMENT AIR PRESSUREPRI"
  6 ." ME OVEN EXHAUST LEL     COLOR OVEN EXHAUST LEL     HYDROGEN"
  7 ."  PRESSURE  DIP OVEN CONTROLLER STATUSPRESSUREEXHAUST TEMPE"
  8 ." RATUREFUME TUNNEL TEMP AT OVEN INCINERATOR CONDITIONSINLET "
  9 ." TEMPERATUREINLET TO CATALYST TEMPCATALYST EXIT TEMP DESTRUC"
 10 ." TION EFFICIENCY--------------------------------------------"
 11 ." -------DAMPER POSITIONS   % OPENDIP OVEN EXHAUST DAMPERDIP "
 12 ." OVEN INLET DAMPERALARM HORN ENABLE SWITCHHIGH ALARMHIGH CAU"
 13 ." TIONSENSOR FAILURELOWOFFAVERAGELOWHIGHCONTROLLER ON-LINEPRE"
 14 ." SSURE  in H2O"
 15


448 LIST

  0 ( STATUS SCREEN STATIC TABLE)
  1 CREATE 1STATIC 33 ,
  2 (  #    X     Y   COLOR   POSITION  LENGTH)
  3 (  1)  27 ,  1 , ' TITL ,    0 ,  23 ,
  4 (  2)   6 ,  3 , ' LABL ,   23 ,  33 ,
  5 (  3)  50 ,  3 , ' LABL ,   56 ,  19 ,
  6 (  4)   0 ,  5 , ' STD  ,   75 ,  22 ,
  7 (  5)   0 ,  7 , ' STD  ,   97 ,  16 ,
  8 (  6)   0 ,  9 , ' STD  ,  113 ,  22 ,
  9 (  7)   0 , 11 , ' STD  ,  135 ,  22 ,
 10 (  8)   0 , 13 , ' STD  ,  157 ,  17 ,
 11 (  9)   0 , 15 , ' STD  ,  174 ,  19 ,
 12 ( 10)   0 , 17 , ' STD  ,  359 ,  11 ,
 13 ( 11)   0 , 19 , ' STD  ,  203 ,   7 ,
 14 ( 12)   4 , 22 , ' STD  ,  210 ,  23 ,
 15


449 LIST

  0   ( STATUS SCREEN STATIC TABLE CONTINUED)
  1 ( 13)   4 , 24 , ' STD  , 233 ,  22 ,
  2 ( 14)   4 , 26 , ' STD  , 260 ,  22 ,
  3 ( 15)   4 , 28 , ' STD  , 287 ,  19 ,
  4 ( 15A)  4 , 30 , ' STD  , 606 ,  24 ,
  5 ( 16)   4 , 32 , ' STD  , 306 ,  26 ,
  6 ( 17)  45 ,  5 , ' STD  , 332 ,   8 ,
  7 ( 18)  45 ,  7 , ' STD  , 340 ,  19 ,
  8 ( 19)  45 ,  9 , ' STD  , 359 ,  25 ,
  9 ( 20)  50 , 11 , ' LABL , 384 ,  22 ,
 10 ( 21)  45 , 13 , ' STD  , 406 ,  17 ,
 11 ( 22)  45 , 15 , ' STD  , 423 ,  22 ,
 12 ( 23)  45 , 17 , ' STD  , 445 ,  19 ,
 13 ( 24)  45 , 19 , ' STD  , 464 ,  22 ,
 14
 15
```

450 LIST

```
  ( STATUS SCREEN STATIC TABLE CONTINUED)
( 25)   0 ,  4 , ' LABL , 486 ,  40 ,
( 26)  50 ,  4 , ' LABL , 486 ,  19 ,
( 27)  50 , 12 , ' LABL , 486 ,  22 ,
( 28)  50 , 21 , ' LABL , 537 ,  25 ,
( 29)  45 , 24 , ' STD  , 562 ,  23 ,
( 30)  45 , 26 , ' STD  , 585 ,  21 ,
( 31)  50 , 22 , ' LABL , 486 ,  25 ,
( 32)   0 , 20 , ' LABL , 486 ,  40 ,
```

451 LIST

```
( STATUS SCREEN ANALOG DATA)
(  #     X       Y     DATAADDR    CONV ROUTINE )
CREATE 1ANALOG  17 ,
(   4)   24 ,   5 ,   FDATA      ,  ' >LEL  ,
(   5)   24 ,   7 ,   FDATA 2 + ,  ' >LEL  ,
(   6)   24 ,   9 ,   FDATA 4 + ,  ' >LEL  ,
(   7)   24 ,  11 ,   FDATA 6 + ,  ' >LEL  ,
(   8)   24 ,  13 ,   FDATA 10 + ,  ' >LEL  ,
(   9)   24 ,  15 ,   FDATA 12 + ,  ' >LELLOW  ,
(  10)   24 ,  17 ,   FDATA 8 + ,  ' >LEL  ,
(  11)   24 ,  19 ,   FDATA 14 + ,  ' >LELLOW  ,
(  17)   68 ,   5 ,   FDATA 16 + ,  ' >PRESS ,
(  18)   70 ,   7 ,   FDATA 18 + ,  ' >TEMP  ,
(  19)   70 ,   9 ,   FDATA 20 + ,  ' >TEMP  ,
```

452 LIST

```
  ( STATUS SCREEN ANALOG DATA CONTINUED)
( 21)   70 ,  13 ,  FDATA 22 +   ,  ' >TEMP  ,
( 22)   70 ,  15 ,  FDATA 24 +   ,  ' >TEMPHIGH ,
( 23)   70 ,  17 ,  FDATA 26 +   ,  ' >TEMPHIGH ,
( 24)   70 ,  19 ,    %DE        ,  ' >%DE      ,
( 29)   70 ,  24 ,    1PO        ,  ' >DP%      ,
( 30)   70 ,  26 ,    2PO        ,  ' >DP%      ,
453 LIST

  0 ( STATUS SCREEN DIGITAL STUFF)
  1 CREATE 1DIGITAL 24 ,
  2 (          X        Y   DATAADDR     TRUMSG    FALSEMSG )
  3 (   4A)   32   ,    5 , ALARMS 14 + , ' 4MSG , ' NULL ,
  4 (   4B)   32   ,    5 , ALARMS  8 + , ' 2MSG , ' NULL ,
  5 (   4C)   32   ,    5 , ALARMS      , ' 3MSG , ' NULL ,
  6 (   4D)   32   ,    5 ,  ALOK       , ' 1MSG , ' NULL ,
  7 (   5A)   32   ,    7 , ALARMS 16 + , ' 4MSG , ' NULL ,
  8 (   5B)   32   ,    7 , ALARMS 10 + , ' 2MSG , ' NULL ,
  9 (   5C)   32   ,    7 , ALARMS  2 + , ' 3MSG , ' NULL ,
 10 (   5D)   32   ,    7 ,  ALOK   2 + , ' 1MSG , ' NULL ,
 11 (   6A)   32   ,    9 , ALARMS 18 + , ' 4MSG , ' NULL ,
 12 (   6C)   32   ,    9 , ALARMS  4 + , ' 3MSG , ' NULL ,
 13 (   6D)   32   ,    9 ,  ALOK   4 + , ' 1MSG , ' NULL ,
 14
 15


454 LIST

  0   ( STATUS SCREEN DIGITAL STUFF CONTINUED)
  1 (   7A)  32   ,   11 , ALARMS 20 + , ' 4MSG , ' NULL ,
  2 (   7C)  32   ,   11 , ALARMS  6 + , ' 3MSG , ' NULL ,
  3 (   7D)  32   ,   11 , ALOK    6 + , ' 1MSG , ' NULL ,
  4 (   8 )  32   ,   13 , ALARMS 24 + , ' 4MSG , ' 1MSG ,
  5 (   9 ) ( 32  ,   15 , ALARMS 26 + , ' 4MSG , ' 1MSG ,)
  6 ( 10A)   32   ,   17 , ALARMS 22 + , ' 4MSG , ' NULL ,
  7 ( 10B)   32   ,   17 , ALARMS 12 + , ' 2MSG , ' NULL ,
  8 ( 10C)   32   ,   17 , ALOK    8 + , ' 1MSG , ' NULL ,
  9
 10
 11
 12
 13
 14
 15


455 LIST

  0   ( STATUS SCREEN DIGITAL STUFF CONTINUED)
  1
  2 ( 12 )   32   ,   22 , ALARMS 30 + , ' 8MSG , ' 1MSG ,
  3 ( 13 )   32   ,   24 , ALARMS 32 + , ' 2MSG , ' 1MSG ,
  4 ( 14 )   32   ,   26 , ALARMS 34 + , ' 2MSG , ' 1MSG ,
  5 ( 15 )   32   ,   28 , ALARMS 28 + , ' 8MSG , ' 1MSG ,
  6 ( 15A)   32   ,   30 , ALARMS 36 + , ' 9MSG , ' 0MSG ,
  7 ( 16 )   32   ,   32 , AUTOCTRL    , ' 6MSG , ' 5MSG ,
  8
  9
 10
 11
 12
 13
 14
 15
```

```
465 LIST

   0 ( MENU RESPONSE WORDS -- CONTROLLER ON)
   1
   2 : OK1  20 43 GOTOXY 7 EMIT NORM
   3        ." DIP OVEN CONTROL IS ALREADY ON "
   4         2000 MS  20 43 GOTOXY 7 EMIT STD EL ;
   5 : OK2  20 43 GOTOXY 7 EMIT CAUT ."  PLEASE TURN THE HORN OFF "
   6        2000 MS  20 43 GOTOXY 7 EMIT STD EL ;
   7 : ?ON      1 AUTOCTRL ! 1 ENABLEHORN ! SAFETY AUTOCTRL @ ;
   8 : 1ON  0 1TRACK  1UPDT   0 2TRACK 2UPDT ;
   9
  10 : CON  AUTOCTRL @ IF OK1   ELSE
  11                WRDOUT @ 1 AND IF  OK2 ELSE
  12                ?ON IF 1ON PROCCTRL
  13       THEN THEN THEN 6 ;
  14
  15


466 LIST

   0 ( MENU RESPONSE WORDS -- CONTROLLER OFF)
   1
   2 : COFF  AUTOCTRL @ NOT IF
   3         20 43 GOTOXY 7 EMIT NORM ." ALREADY IN MONITOR MODE "
   4         2000 MS  20 43 GOTOXY 7 EMIT STD EL
   5            ELSE  MANUAL THEN 6 ;
   6
   7
   8
   9
  10
  11
  12
  13
  14
  15


467 LIST

   0 ( MENU RESPONSE WORDS -- HORN OFF)
   1
   2 : HORNOFF  WRDOUT @ 1 AND NOT IF
   3            20 43 GOTOXY 7 EMIT NORM ." THE HORN IS ALREADY OFF "
   4             2000 MS  20 43 GOTOXY 7 EMIT STD EL
   5            ELSE  0 ENABLEHORN ! WRDOUT @ 14 AND DUP WRDOUT !
   6            202 OUTPUT THEN 6 ;
   7          ( 202 DECIMAL = CA HEX)
   8
   9
  10
  11
  12
  13
  14
  15
```

```
468 LIST

( MENU RESPONSE WORDS -- PRINT REPORT)

: REPPRINT  1 ?REPORT !  NORM 10 43 GOTOXY
 ." REPORT SEQUENCE BEGUN PRINTER WILL START MOMENTARILY"
  2000 MS 10 43 GOTOXY STD EL 6 ;
```

```
469 LIST
```

```
470 LIST
```

```
483 LIST

( MAIN MENU)

: BODY  ( REQUIRES AN ASCII CHAR ON STACK)
        DUP 49 = IF INVF ELSE LABL THEN 20 16 GOTOXY
        ." TO DISPLAY STATUS SCREEN    -- PRESS 1 "
        DUP 50 = IF INVF ELSE LABL THEN 20 19 GOTOXY
        ." TO SET SYSTEM CLOCK         -- PRESS 2 "
        DUP 51 = IF INVF ELSE LABL THEN 20 22 GOTOXY
        ." TO SET CONTROL CONSTANTS    -- PRESS 3 "
        DUP 52 = IF INVF ELSE LABL THEN 20 25 GOTOXY
        ." TO PRINT A SUMMARY REPORT   -- PRESS 4 "
        DUP 53 = IF INVF ELSE LABL THEN 20 28 GOTOXY
        ." BULLDOG                     -- PRESS 5 "
        DROP  STD  80 0 GOTOXY ;
```

```
484 LIST

( MAIN MENU CONT)

: MENUTITLE  STD PAGE 10 6 GOTOXY SDH SBG RED 24 SPACES
             SBG BLCK  ."  M E N U  "
             SBG BLUE  24 SPACES
             VERTICAL 15 SPACES NORMAL
             10 6 GOTOXY SBG RED VERTICAL 15 SPACES
             NORMAL SBG WHITE 59 SPACES
             STD SSH ;
```

```
485 LIST

( MAIN MENU WORDS CONT)
: ?VALID  ( ASCII CHAR ON STACK RETURNS 0 OR 1)
          DUP 13 = IF DROP 1 ELSE
          49 54 WITHIN THEN ;

CREATE MENULIST  6 C, 7 C, 0 C, 5 C, 8 C,
: CHANGO  49 - MENULIST + C@ ;

: ?END  6 150 0 DO 100 MS 216 INPUT DUP PRIOR @ = NOT IF
       DUP ?VALID IF DUP 13 = IF PRIOR @ SWAP PRIOR ! DUP
       ?VALID IF SWAP DROP CHANGO LEAVE ELSE DROP THEN ELSE
       DUP PRIOR ! BODY THEN ELSE PRIOR ! BAD 0 BODY THEN
       ELSE DROP THEN LOOP ;
```

```
486 LIST

  0 ( MAIN MENU WORDS CONT)
  1
  2 : MENU   1 ?REFRESH !  MENUTITLE 0 BODY ?END ;
  3
  4
  5
  6
  7
  8
  9
 10
 11
 12
 13
 14
 15

487 LIST

488 LIST
```

```
489 LIST

   0 ( PASSWORD SCREEN WORDS)
   1 CREATE 2WORDS
   2 ." CONTROLLER CONSTANTSPLEASE ENTER PASSWORDOVEN LEL LOOP  CUR"
   3 ." RENT          NEWSET POINTGAINDERIVINTEGOVEN PRESSURE LOOP PA"
   4 ." RAMETERS  MAX DAMPER CHANGE (% PER CYCLE)LOOP TIME INTERVAL"
   5 ."  (SECONDS)      When the cursor blinks in an area,enter the "
   6 ." new value or press the RETURN key to retain the current val"
   7 ." ue  REPORTINGHOUR TO BEGIN DATA COLLECTION (0-23)HOUR TO "
   8 ." PRINT REPORT (0-23)"
   9
  10
  11
  12
  13
  14
  15
```

```
490 LIST

   0 ( PASSWORD SCREEN STATIC TABLE)
   1 CREATE 2STATIC 23 ,
   2 (  1)  30  ,  1  , ' TITL  ,   0 ,   20 ,
   3 (  2)  15  ,  3  , ' LABL  ,  20 ,   21 ,
   4 (  3)  15  ,  5  , ' LABL  ,  41 ,   33 ,
   5 (  4)  18  ,  7  , ' STD   ,  74 ,    9 ,
   6 (  5)  22  ,  9  , ' STD   ,  83 ,    4 ,
   7 (  6)  22  , 11  , ' STD   ,  87 ,    5 ,
   8 (  7)  22  , 13  , ' STD   ,  92 ,    5 ,
   9 (  8)  15  , 16  , ' LABL  ,  97 ,   18 ,
  10 (  9)  18  , 18  , ' STD   ,  74 ,    9 ,
  11 ( 10)  22  , 20  , ' STD   ,  83 ,    4 ,
  12 ( 11)  22  , 22  , ' STD   ,  87 ,    5 ,
  13 ( 12)  22  , 24  , ' STD   ,  92 ,    5 ,
  14
  15
```

```
491 LIST

   0 ( PASSWORD SCREEN STATIC TABLE CONTINUED)
   1 ( 13)  15  , 27  , ' LABL  , 111 ,   15 ,
   2 ( 13A) 51  , 27  , ' LABL  ,  56 ,    7 ,
   3 ( 13B) 62  , 27  , ' LABL  ,  71 ,    3 ,
   4 ( 14)  18  , 29  , ' STD   , 128 ,   31 ,
   5 ( 15)  18  , 31  , ' STD   , 159 ,   28 ,
   6 ( 16)  15  , 40  , ' LABL  , 192 ,   34 ,
   7 ( 17)  15  , 41  , ' LABL  , 226 ,   39 ,
   8 ( 18)  15  , 42  , ' LABL  , 266 ,   33 ,
   9 ( 19)  15  , 34  , ' LABL  , 299 ,    9 ,
  10 ( 20)  18  , 36  , ' STD   , 308 ,   36 ,
  11 ( 21)  18  , 38  , ' STD   , 344 ,   27 ,
  12
  13
  14
  15
```

```
492 LIST

( PASSWORD SCREEN CURRENT VALUE TABLE)
CREATE 2DATA  12 ,
(  4)  30  ,  7 ,  1SP  ,   ' >LEL   ,
(  5)  30  ,  9 ,  1KC  ,   ' >PLAIN ,
(  6)  30  , 11 ,  1TD  ,   ' >PLAIN ,
(  7)  30  , 13 ,  1TI  ,   ' >PLAIN ,
(  9)  30  , 18 ,  2SP  ,   ' >PRESS ,
( 10)  30  , 20 ,  2KC  ,   ' >PLAIN ,
( 11)  30  , 22 ,  2TD  ,   ' >PLAIN ,
( 12)  30  , 24 ,  2TI  ,   ' >PLAIN ,
( 14)  51  , 29 ,  dCH  ,   ' >LEL   ,
( 15)  51  , 31 ,  dt   ,   ' >PLAIN ,
( 20)  55  , 36 , BEGIN-HR  , ' >PLAIN ,
( 21)  55  , 38 , REPORT-HR , ' >PLAIN ,



493 LIST

( PASSWORD SCREEN VALUE CHANGING TABLE)
CREATE CTRLCONST  12 ,
(  4)  45 ,  7 ,  1SP ,  ' >LEL   , ' LEL> , 40 ,  5 ,
(  5)  45 ,  9 ,  1KC ,  ' >PLAIN , ' NULL , 20 ,  1 ,
(  6)  45 , 11 ,  1TD ,  ' >PLAIN , ' NULL , 10 ,  0 ,
(  7)  45 , 13 ,  1TI ,  ' >PLAIN , ' NULL , 100 , 1 ,
(  9)  45 , 18 ,  2SP ,  ' >PRESS , ' PRESS> , 0 , -5 ,
( 10)  45 , 20 ,  2KC ,  ' >PLAIN , ' NULL , 20 , 1 ,
( 11)  45 , 22 ,  2TD ,  ' >PLAIN , ' NULL , 10 , 0 ,
( 12)  45 , 24 ,  2TI ,  ' >PLAIN , ' NULL , 100 , 1 ,
( 14)  62 , 29 ,  dCH ,  ' >LEL   , ' LEL> , 100 , 1 ,
( 15)  62 , 31 ,  dt  ,  ' >PLAIN , ' NULL , 5 , 1 ,
( 20)  62 , 36 , BEGIN-HR  , ' >PLAIN , ' NULL , 23 , 0 ,
( 21)  62 , 38 , REPORT-HR , ' >PLAIN , ' NULL , 23 , 0 ,



494 LIST
```

```
495 LIST

   0 ( PASSWORD SCREEN WORDS)
   1 : ?ANYIN  DUP POSITION NORM 5 SPACES DUP POSITION
   2           S0 @ 80 BLANK S0 @ 5 EXPECT 0 >IN ! CNT @ ;
   3
   4 : ?INVALID  S0 @ CNT @ 0 DO DUP I + C@ 32 = NOT IF DROP I LEAVE
   5             THEN LOOP DUP 6 > IF DROP 0 ELSE >IN ! 46 WORD DUP
   6             1+ C@ 45 = IF 2 ELSE 1 THEN OVER C@ 1+ SWAP DO DUP
   7             I + C@ 48 58 WITHIN NOT IF DROP 0 LEAVE THEN LOOP
   8             THEN NOT ;
   9
  10
  11
  12
  13
  14
  15


496 LIST

   0 ( PASSWORD SCREEN WORDS)
   1
   2 : RNGERR  20 43 GOTOXY  CAUT ."  < OUT OF RANGE ERROR > "
   3           20 43 GOTOXY  STD  4 0 DO 7 EMIT 500 MS LOOP EL ;
   4
   5 : CHECK  HERE NUMBER OVER 2DUP ROT 12 + @ SWAP 10 + @ 1+
   6          WITHIN IF OVER POSITION OVER 8 + @ EXECUTE 2DUP SWAP
   7          6 + @ EXECUTE SWAP 4 + @ ! 1 ELSE RNGERR DROP 0 THEN ;
   8
   9
  10 : CHNGVAL  BEGIN  ?ANYIN IF ?INVALID IF BAD 0 ELSE CHECK THEN
  11            ELSE DUP POSITION DUP 4 + @ @ SWAP 6 + @ EXECUTE 1
  12            THEN END ;
  13
  14
  15


497 LIST

   0 ( PASSWORD SCREEN WORDS)
   1
   2 CREATE PASSWORD  ." 41678"
   3
   4 : ?PASSWORD  38 3 GOTOXY NONE 10 SPACES 38 3 GOTOXY NONE
   5              S0 @ 10 EXPECT STD PASSWORD 5 S0 @ -TEXT NOT ;
   6
   7
   8
   9
  10
  11
  12
  13
  14
  15
```

```
498 LIST

      0 (  PASSWORD SCREEN FINAL WORDS)
      1 : CONTROL-PARAMS
      2          2WORDS 'WORDSSTATIC !  2STATIC  'TABLESTATIC !
      3          2DATA  'DISPVALUE   !  STD PAGE STAT ANALO ?PASSWORD IF
      4      CTRLCONST DUP @ 14 * OVER + SWAP 2+ DO I CHNGVAL 14 +LOOP
      5        ELSE BAD THEN 80 0 GOTOXY 1 ?REFRESH ! 3000 MS STD 6 ;
      6
      7
      8
      9
     10
     11
     12
     13
     14
     15

499 LIST

500 LIST
```

```
501 LIST

 ( SET CLOCK SCREEN)

 CREATE XYPOS 48 , 11 , 48 , 13 , 48 , 18 , 48 , 20 , 48 , 22 ,
 CREATE TIMERANGE  0 , 60 , 0 , 24 , 1 , 32 , 1 , 13 , 0 , 100 ,

 : ?RANGE  ( ADDR OF LOW RANGE , # -> 0 OR # , 1)
   DUP ROT DUP @ SWAP 2+ @ WITHIN IF 1 ELSE DROP 0 RNGERR THEN ;

 : #GET  4 * BEGIN  DUP XYPOS + ?ANYIN IF ?INVALID IF
         BAD DROP 0 ELSE DROP DUP TIMERANGE + HERE NUMBER ?RANGE
         THEN ELSE DROP 0 THEN END SWAP DROP STD ;
```

```
502 LIST

 ( SET CLOCK SCREEN)


 : *TIMESET  18 7 GOTOXY LABL ." CLOCK BOARD SWITCH MUST BE IN "
             NORM ." ENABLE" LABL ."  POSITION"
             18 9 GOTOXY
     ." DO YOU WISH TO SET TIME? (Y OR N)  " KEY 89 = IF
     STD 21 11 GOTOXY ." ENTER MINUTE (0 TO 59)" 0 #GET
     STD 21 13 GOTOXY ." ENTER HOUR   (0 TO 23)" 1 #GET
     TIMESET THEN ;
```

```
503 LIST

 ( SET CLOCK SCREEN)

 : TWIDDLE
     STD 21 18 GOTOXY ." ENTER DAY     (1 TO 31)  " 2 #GET
     STD 21 20 GOTOXY ." ENTER MONTH   (0 TO 23)  " 3 #GET
     STD 21 22 GOTOXY ." ENTER YEAR    (0 TO 99)  " 4 #GET ;

 : *DATESET   LABL  18 16 GOTOXY
     ." DO YOU WISH TO SET DATE? (Y OR N)  " KEY 89 = IF
     TWIDDLE DATESET THEN ;
```

```
504 LIST

( SET CLOCK SCREEN)


: SECURITY  LABL  18 3 GOTOXY ." ENTER PASSWORD " ?PASSWORD
            STD ;


: SET-THE-CLOCK  SECURITY IF *TIMESET  *DATESET ELSE BAD
                 THEN  ;
```

```
505 LIST

( SET CLOCK SCREEN)

: SETCLOCK  PAGE  32 1 GOTOXY  TITL ." SET SYSTEM CLOCK"
            SSH AUTOCTRL @ IF 7 EMIT 15 6 GOTOXY NORM
    ." SYSTEM CLOCK MAY ONLY BE SET WHILE IN MONITOR MODE"
  STD  ELSE  SET-THE-CLOCK THEN 5000 MS 6 ;
```

```
506 LIST
```

```
507 LIST

   0 ( BULLDOG SCREEN OUTLINE TABLE)
   1  FORTH  : $  SWAP  C, C, ;
   2 CREATE OUTLINE  34 38 $ 32 42 $ 40 45 $ 42 45 $ 40 50 $ 38 62 $
   3 38 82 $ 34 90 $ 26 98 $ 18 102 $ 18 110 $ 22 114 $ 22 122 $
   4 26 126 $ 26 130 $ 34 138 $ 50 138 $ 58 134 $ 66 134 $ 74 126 $
   5 70 122 $ 70 114 $ 66 110 $ 110 110 $ 118 108 $ 130 98 $
   6 134 86 $ 142 78 $ 142 58 $ 146 54 $ 146 34 $ 142 30 $ 134 30 $
   7 130 34 $ 130 38 $ 134 42 $ 134 50 $ 130 60 $ 126 70 $ 118 78 $
   8 114 78 $ 98 62 $ 98 22 $ 90 19 $  82 22 $ 82 52 $
   9 78 54 $ 78 46 $ 74 42 $ 81 36 $ 81 53 $ 70 62 $ 58 62 $
  10 54 58 $ 54 42 $ 50 38 $ 34 38 $ 0 0 $
  11
  12
  13
  14
  15
```

```
508 LIST

   0    ( BULLDOG OUTLINE)
   1
   2 -5 CONSTANT XFACT   20 CONSTANT YFACT
   3
   4 : *OUTLINE  GRAPH  OUTLINE DUP C@ XFACT + EMIT
   5            DUP 1+ C@ YFACT + EMIT
   6     VECTOR  BEGIN 2+ DUP C@ ?DUP IF XFACT + EMIT DUP
   7     1+ C@ YFACT + EMIT 0 ELSE DROP 1 THEN END ALPHA ;
   8
   9
  10
  11
  12
  13
  14
  15
```

```
509 LIST

   0     ( BULLDOG 2 SEGMENT LINES)
   1
   2 CREATE 2SEG                      54 134 $ 56 131 $ 60 134 $
   3 48 130 $ 50 132 $ 58 127 $      60 130 $ 64 134 $ 70 130 $
   4 70 130 $ 72 126 $ 74 114 $      74 114 $ 74 106 $ 70 96  $
   5 86 130 $ 86 126 $ 82 122 $      90 114 $ 86 122 $ 88 114 $
   6 50 110 $ 62 102 $ 68 94  $      154 42 $ 156 38 $ 150 34 $
   7 166 42 $ 156 38 $ 164 32 $      110 19 $ 110 26 $ 110 19 $
   8 58 70  $ 74  58 $ 58 70  $      90 62  $ 94 70  $ 106 82 $
   9 130 106 $138 96 $ 142 82 $      124 106$ 132 92 $ 132 80 $
  10 110 106 $118 98 $ 118 70 $      118 70 $ 119 90 $ 98 106 $
  11 102 27 $ 110 26 $ 118 27 $
  12 0 0 $
  13
  14
  15
```

```
510 LIST

  ( BULLDOG 2 SEGMENT)

-25 CONSTANT XFACT  20 CONSTANT YFACT

: CYCLE   POINT XFACT + EMIT DUP 1+ C@ YFACT + EMIT
          VECTOR
          DUP 2+ C@ XFACT + EMIT DUP 3 + C@ YFACT + EMIT
          DUP 4 + C@ XFACT + EMIT DUP 5 + C@ YFACT + EMIT
          6 + PAUSE ;

: *2SEG  GRAPH   2SEG BEGIN DUP C@ ?DUP IF CYCLE 0 ELSE DROP 1
          THEN END ALPHA ;




```

```
511 LIST

   ( BULLDOG 3 SEGMENT)
CREATE 3SEG
48 126 $ 52 129 $ 52 126 $ 48 126 $
62 126 $ 62 128 $ 66 126 $ 62 126 $
64 120 $ 68 115 $ 66 110 $ 64 105 $
42 122 $ 54 122 $ 58 116 $ 58 110 $
62 94  $ 50 108 $ 46 108 $ 46 98  $
46 98  $ 42 106 $ 42 110 $ 50 110 $
54 90  $ 62 90  $ 70 94  $ 86 110 $
58 78  $ 70 78  $ 78 84  $ 102 110 $
102 26 $ 110 30 $ 118 26 $ 102 26 $
62 45  $ 66 42  $ 63 41 $  63 38  $
66 42  $ 74 42  $ 62 63 $  58 64  $
0 0 $


```

```
512 LIST

  ( BULLDOG 3 SEGMENT)


: 3CYCLE   POINT XFACT + EMIT DUP 1+ C@ YFACT + EMIT
          VECTOR
          DUP 2 + C@ XFACT + EMIT DUP 3 + C@ YFACT + EMIT
          DUP 4 + C@ XFACT + EMIT DUP 5 + C@ YFACT + EMIT
          DUP 6 + C@ XFACT + EMIT DUP 7 + C@ YFACT + EMIT
          8 + PAUSE ;

: *3SEG GRAPH  3SEG BEGIN DUP C@ ?DUP IF 3CYCLE 0 ELSE DROP 1
          THEN END ALPHA ;

: NOSE  GRAPH 46 XFACT + EMIT  118 YFACT + EMIT
              50 XFACT + EMIT  118 YFACT + EMIT ALPHA ;

```

```
513 LIST

   ( BULLDOG)

 : BORDER  SBG RED  0 0 GOTOXY 79 SPACES VERTICAL 46 SPACES
           RTOL 80 SPACES 0 0 GOTOXY VERTICAL 46 SPACES
           NORMAL
           SBG BLUE 1 1 GOTOXY 77 SPACES VERTICAL 44 SPACES
           RTOL 78 SPACES 1 1 GOTOXY VERTICAL 44 SPACES
           NORMAL STD 0 0 GOTOXY ;
```

```
514 LIST

     ( BULLDOG)


 : MT   45 6 GOTOXY SFG WHITE SBG BLUE SDH ."  M A C K "
        43 10 GOTOXY  ."  T R U C K S "
        SSH STD ;
```

```
515 LIST

 ( BULLDOG)


 : BULLDOG    PAGE STD SFG
              *OUTLINE 100 MS
              *2SEG 100 MS
              *3SEG 100 MS
              NOSE STD
              BORDER MT
              18 47 GOTOXY LABL
              ." PRESS ANY KEY TO RETURN TO STATUS SCREEN"
              80 0 GOTOXY KEY DROP 6 STD ;
```

```
534 LIST

( INITIALIZE SCREEN DRIVER VARIABLES)

: 9INIT   13  PRIOR  !
            ['] STATUS-SCREEN  'STATUS-SCREEN  !
            ['] CON       'CON      !
            ['] COFF      'COFF     !
            ['] HORNOFF  'HORNOFF !
            ['] REPPRINT  'REPORT !
            ['] SETCLOCK 'SETCLOCK !
            ['] BULLDOG   'BULLDOG  !
            ['] MENU      'MENU     !
            ['] CONTROL-PARAMS   'CONTROL-PARAMS !  ;
```

```
535 LIST
```

```
536 LIST
```

```
537 LIST

( REPORT GENERATING VARIABLES)
VARIABLE TEMPORARY  #ALARMS 2* ALLOT
VARIABLE LSTALRM    #ALARMS 2* ALLOT
VARIABLE HIGHDATA   32 ALLOT
VARIABLE LOWDATA    32 ALLOT
VARIABLE AVGDATA    64 ALLOT
VARIABLE #RECS

VARIABLE FLAG
VARIABLE TIMEBASE   2 ALLOT
VARIABLE TICKER
 15  CONSTANT  INTERVAL

#ALARMS 2*
: 7INIT     0 TICKER !  LSTALRM IN-LINE ERASE
            8 BEGIN-HR !  17 REPORT-HR ! 0 FLAG ! ;
```

```
538 LIST

( ALARM WORD TABLE FOR REPORT)
CREATE ALWRDTBLE
(  0)   75 ,  22 ,  630 ,  10 ,
(  1)   97 ,  16 ,  630 ,  10 ,
(  2)  113 ,  22 ,  630 ,  10 ,
(  3)  135 ,  22 ,  630 ,  10 ,
(  4)   75 ,  22 ,  640 ,  12 ,
(  5)   97 ,  16 ,  640 ,  12 ,
(  6)  359 ,  11 ,  640 ,  12 ,







```

```
539 LIST

    ( ALARM WORD TABLE FOR REPORT CONTINUED)

(  7)   75 ,  22 ,  652 ,  14 ,
(  8)   97 ,  16 ,  652 ,  14 ,
(  9)  113 ,  22 ,  652 ,  14 ,
( 10)  135 ,  22 ,  652 ,  14 ,
( 11)  359 ,  11 ,  652 ,  14 ,
( 12)  157 ,  17 ,  652 ,  14 ,
( 13)  174 ,  19 ,  652 ,  14 ,
( 14)  287 ,  17 ,  666 ,   3 ,
( 15)  666 ,   3 ,  210 ,  23 ,
( 16)  233 ,  22 ,  640 ,  12 ,
( 17)  260 ,  22 ,  640 ,  12 ,
( 18)  606 ,  24 ,  669 ,   3 ,


540 LIST

     0 ( PRINT ALARMS)
     1
     2 : ALMLABLE    ( ALARM # ON STACK -> LEAVES # CHARS TYPED)
     3               8 * ALWRDTBLE + DUP @ 1WORDS + OVER 2+
     4               @ DUP >R TYPE SPACE DUP 4 + @ 1WORDS + SWAP 6 +
     5               @ DUP >R TYPE  R>  R>  + 1+ ;
     6
     7 #ALARMS 2*
     8 : PRINTALARM  ( RECORD NUMBER ON STACK)
     9          DATE TIME CR  ALARMS TEMPORARY IN-LINE MOVE
    10          #ALARMS 0 DO  I 2* DUP TEMPORARY + @ SWAP LSTALRM + @ -
    11          ?DUP IF  20 SPACES  I ALMLABLE 40 SWAP - SPACES
    12          0 > IF ."  ON" ELSE ."  OFF" THEN
    13          CR  THEN LOOP CR ;
    14
    15


541 LIST

     0 ( PRINT ALARMS CONTINUED)
     1
     2
     3 : ?NEWALARM  LSTALRM  #ALARMS 2*  ALARMS -TEXT
     4              IF PRINTALARM
     5              TEMPORARY LSTALRM #ALARMS 2* MOVE THEN ;
     6
     7
     8
     9
    10
    11
    12
    13
    14
    15

542 LIST
```

```
543 LIST

( DATA ANALYSIS)
: INITDATAANAL  0 #RECS !  HIGHDATA 32 ERASE
        AVGDATA 64 ERASE
        LOWDATA DUP 32 + SWAP DO 4095 I ! 2 +LOOP
        HR TIMEBASE ! MINUTE TIMEBASE 2+ ! ;

: ANALDATA  1 #RECS  +! FDATA TEMPORARY 28 MOVE
                 TEMPORARY %DE @ OVER 28 + !
                 AUTOCTRL @ 1000 * SWAP 30 + !
     32 0 DO AVGDATA I 2* + DUP 2@ TEMPORARY I + @ 0 D+
     ROT 2!   TEMPORARY I + @ DUP LOWDATA I + @ < IF
     LOWDATA I + ! ELSE DUP HIGHDATA I + @ > IF
     HIGHDATA I + ! ELSE DROP THEN THEN 2 +LOOP ;



544 LIST

( TIME TO UPDATE DATA ANALYSIS)


: ?ANALYZE  TICKER @ INTERVAL < IF 1 TICKER +!  ELSE
            0 TICKER ! ANALDATA THEN ;













545 LIST
```

```
546 LIST

( ALARM REPORT HEADING AND ENDING)



: ALARMHEAD   PAGE  5 0 DO CR LOOP
          29 SPACES ." MACK TRUCKS" CR CR
          25 SPACES ." ALARM STATUS REPORT" CR CR CR CR
          5 SPACES ." TIME" 20 SPACES ." ALARM" 26 SPACES
          ." STATUS" CR 70 0 DO ." -" LOOP  CR ;
: ENDALARMREP  CR  ." END OF ALARM REPORT  " DATE  TIME ;





547 LIST

( DATA REPORT HEADING)

: PERIOD  ." FOR TIME PERIOD   " TIMEBASE @ .HR ." :"
        TIMEBASE 2+ @ .MIN
       ." -- TO -- " DATE TIME CR CR CR ;

: REPORTHEAD   PAGE  5 0 DO CR LOOP
          29 SPACES ." MACK TRUCKS" CR CR
          25 SPACES ."   DATA LOG SHEET   " CR CR CR CR PERIOD
          26 SPACES ." AVERAGE" 8 SPACES ." LOW" 11 SPACES
          ." HIGH " CR 100 MS  70 0 DO ." -"  LOOP  CR CR ;





548 LIST

( DATA REPORT ENDING)

: UNDLNE  ." 
  _________ _________ _______ ______ ________" ;
: 2BOTTOM  CR CR ." STEAM AND FUEL FLOWS" CR 70 0 DO ." -" LOOP
     CR CR 20 SPACES ." RATE #/Hr  TOTALIZER  TEMP(F)  PRESS
  TIME" CR CR CR ." STEAM CONDENSATE    " UNDLNE CR CR CR
          ." INCINERATOR FUEL    " UNDLNE ;







```

```
549 LIST

   0 ( DATA REPORT WORD INDEX TABLE )
   1 CREATE DATATABLE   26 ,
   2 ( #    POS   LEN   ?DATA   DATAPOS  'PRINTROUTINE)
   3 (  2)   23 ,  11 ,  0 ,  0 ,   0 ,
   4 (  -)  486 ,  25 ,  0 ,  0 ,   0 ,
   5 (  4)   75 ,  22 ,  1 ,  0 ,   ' >LEL   ,
   6 (  5)   97 ,  16 ,  1 ,  1 ,   ' >LEL   ,
   7 (  6)  113 ,  22 ,  1 ,  2 ,   ' >LEL   ,
   8 (  7)  135 ,  22 ,  1 ,  3 ,   ' >LEL   ,
   9 (  8)  157 ,  17 ,  1 ,  5 ,   ' >LEL   ,
  10 (  9)  174 ,  19 ,  1 ,  6 ,   ' >LELLOW ,
  11 ( 10)  359 ,  11 ,  1 ,  4 ,   ' >LEL   ,
  12 ( 11)  203 ,   7 ,  1 ,  7 ,   ' >LELLOW ,
  13
  14
  15


550 LIST

   0 ( DATA REPORT WORD INDEX TABLE )
   1 (   )   35 ,   1 ,  0 ,  0 ,   0 ,
   2 (   )   35 ,   1 ,  0 ,  0 ,   0 ,
   3 (  3)   56 ,  19 ,  0 ,  0 ,   0 ,
   4 (  -)  486 ,  25 ,  0 ,  0 ,   0 ,
   5 ( 17)  704 ,  16 ,  1 ,  8 ,   ' >2PRESS  ,
   6 ( 18)  340 ,  19 ,  1 ,  9 ,   ' >TEMP  ,
   7 ( 19)  359 ,  25 ,  1 , 10 ,   ' >TEMP  ,
   8 ( OL)  686 ,  18 ,  1 , 15 ,   ' >%DE   ,
   9 (   )   35 ,   1 ,  0 ,  0 ,   0 ,
  10 (   )   35 ,   1 ,  0 ,  0 ,   0 ,
  11 ( 20)  384 ,  22 ,  0 ,  0 ,   0 ,
  12 (  -)  486 ,  25 ,  0 ,  0 ,   0 ,
  13 ( 21)  406 ,  17 ,  1 , 11 ,   ' >TEMP   ,
  14
  15


551 LIST

   0 ( DATA REPORT WORD INDEX TABLE )
   1 ( 22)  423 ,  22 ,  1 , 12 ,   ' >TEMPHIGH ,
   2 ( 23)  445 ,  19 ,  1 , 13 ,   ' >TEMPHIGH ,
   3 ( 24)  464 ,  22 ,  1 , 14 ,   ' >%DE   ,
   4
   5
   6
   7
   8
   9
  10
  11
  12
  13
  14
  15
```

```
552 LIST

( GENERATE DATA REPORT)
: TYWRDS  DUP @ 1WORDS + OVER 2+ @ TYPE 2+ @ 25 SWAP - SPACES ;

: 1DATAREPORT DATATABLE DUP @ 10 * OVER
     + SWAP 2+ DO  CR 200 MS I TYWRDS
      I 4 + @ IF  I 6 + @ DUP 4 * AVGDATA + 2@ #RECS @ M/
     I 8 + @ EXECUTE 7 SPACES DUP 2* LOWDATA + @ I 8 + @
     EXECUTE 7 SPACES 2* HIGHDATA + @ I 8 + @ EXECUTE THEN
    10 +LOOP ;

: DATAREPORT  REPORTHEAD #RECS @ IF 1DATAREPORT ELSE
     ."  NO DATA TAKEN YET" THEN CR CR 2BOTTOM CR ;
```

```
553 LIST

   ( REPORT GENERATOR CONTINUED)
: REPORT  ?REPORT @ IF
          ENDALARMREP DATAREPORT ALARMHEAD 0 ?REPORT ! THEN ;

: AUTOREP  REPORT-HR @ HR = IF FLAG @ NOT IF 1 FLAG !
           1 ?REPORT ! REPORT INITDATAANAL THEN THEN ;

: BEGIN-COLLECT  BEGIN-HR @ HR = IF FLAG @ IF 0 FLAG !
                 INITDATAANAL THEN THEN ;
```

```
554 LIST

( BACKGROUND TASK -- REPORT GENERATING)

: DATABASE  PRINTER ACTIVATE INITDATAANAL ALARMHEAD
            BEGIN ?NEWALARM ?ANALYZE
            AUTOREP BEGIN-COLLECT REPORT 1800 MS 0 END ;
```

```
555 LIST

( CONTROLLER STARTUP)

: INITVAR   1INIT  2INIT  3INIT  4INIT  5INIT  6INIT
            7INIT  8INIT  9INIT  ;

: GO   INITVAR   0 EXHDAMP  0 INDAMP
       ACQDATA  1000 MS ALARMER  DATABASE
       27 EMIT 70 EMIT 6 DRIVER ;
```

```
556 LIST
```

```
557 LIST
```

```
561 LIST

  0 ( APPLICATION 8086 METAFORTH)   HEX   HOST DEFINITIONS
  1 FORGET ALLOT    : ALLOT    'R FORTH +! ;    HOST
  2 8000 EQU ORIGIN    ORIGIN 10 / ( MINUS) EQU ZERO
  3    8 DICTIONARY  0 WINDOW  1 ORG  ORIGIN 40 + ALLOT
  4 CODE X   HERE 8 - HEAD FORTH !   HEAD DUP 2+ 0E MOVE
  5    2080 PREVIOUS 8 - HOST !   DECIMAL
  6
  7 ( NUCLEUS)  123 131 THRU   ( COMPILER)  96 98 THRU
  8    FORGET CVARIABLE
  9 ( LEVEL 1)  132 134 THRU   ( MULTI-TASK)  135 136 THRU
 10 ( TERMINAL)  138 LOAD   ( OUTPUT)  144 146 THRU 318 LOAD
 11 ( INTERPRETER)  147 150 THRU
 12 ( COMPILER)   159 164 THRU
 13    HEX  CR  HERE U.  THERE U.  DECIMAL
 14 ( ASSEMBLER)    172 LOAD
 15 562 LOAD


562 LIST

  0 ( APPLICATION CONTINUED)
  1 : EMIT   'S 1 TYPE DROP ;
  2 : KEY   CNT @  0 'S 1 EXPECT  SWAP CNT ! ;
  3 ( 32-BIT)  573 LOAD 31 33 THRU
  4 ( EXTENSIONS) 11 LOAD 34 LOAD 572 LOAD  37 38 THRU
  5
  6 HEX  F000   CREATE OPERATOR 60 - ,  DECIMAL
  7 ( TERMINAL)  137 LOAD  141 LOAD 143 LOAD
  8 ( POLLED AND TERM I/O) 114 115 THRU
  9 ( INITAL RAM) 564 LOAD
 10 ( REAL TIME CLOCK) 577 578 THRU 103 LOAD
 11 ( TASK AREAS)  565 LOAD
 12 ( OPERATOR TERMINAL) 139 LOAD
 13  563 LOAD
 14
 15


563 LIST

  0 ( APPLICATION CONTINUED)
  1
  2 ( CONTROLLER)  309 LOAD
  3 ( INITIALIZE OPERATOR) 569 LOAD
  4 ( MISC INTERRUPTS) 566 LOAD
  5
  6 ( INITIALIZE I/O) 567 568 THRU
  7 ( POWER UP )  570 571 THRU  HEX
  8
  9 ( LINKS)  HOST  HEAD RAM 2+ 10 MOVE
 10 ( VECTOR SEED)  ZERO <IRET>  ORIGIN 4 - 2!
 11    CR  HERE U.  THERE U.  DECIMAL   FLUSH
 12
 13
 14
 15
```

```
564 LIST

( INITIAL RAM)   HEX
¶ VARIABLE TEST    VARIABLE TODAY 4 ALLOT ( TODAY , TICKS)

¶ CREATE RAM   51 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,  0 ,
   51 ,  0 ,  0 ,  0 ,  ' (NUMBER) ,
   0 ,  0 ,  0 ,



DECIMAL







565 LIST

( TASK AREAS FOR TARGET COMPILE) HEX
( 1AREA)  40 ALLOT THERE 40 ALLOT THERE CREATE 1AREA , 20 ALLOT
CREATE '1AREA EA2E , OPERATOR @ , ZERO , 0 , ,

( 2AREA)  40 ALLOT THERE 40 ALLOT THERE CREATE 2AREA , 20 ALLOT
CREATE '2AREA EA2E , 1AREA @ , ZERO , 0 , ,

( 3AREA)  40 ALLOT THERE 40 ALLOT THERE CREATE 3AREA , 20 ALLOT
CREATE '3AREA EA2E , 2AREA @ , ZERO , 0 , ,

( PRINTER)   THERE ( H) 200 ALLOT THERE ( S0) 80 ALLOT
THERE CREATE PRINTER , 60 ALLOT
CREATE 'PRINTER EA2E , 3AREA @ , ZERO , 0 , , 0 , 0 , ' (CR) ,
' (PAGE) , ' (TYPE) , 80 , 80 , ' (EXPECT) , DUP , , 0 , 0 ,
0A ,
DECIMAL


566 LIST

( MISC INTERRUPTS)  HEX

HERE ] 3KILL 4 CA OUTPUT SBG RED SFG BLCK PAGE SDH
       ABORT"  POSSIBLE CPU OR MEMORY FAILURE" [
CREATE <TIMO> ASSEMBLER  # I MOV   STI   NEXT

FORTH : BIAS   0  ZERO 10 M*  D+  OPERATOR @ 0 D-
   OPERATOR @ SWAP  10 M/ SWAP ;

¶ CREATE INTERRUPTS
ZERO <CLOCK> , , <TYPE> BIAS , , <EXPECT> BIAS , ,
ZERO <IRET>  , , ZERO <TIMO> , ,

DECIMAL


```

```
567 LIST

     0    ( INITIALIZE I/O)   HEX
     1 ¶ CREATE OWN   ( USART)  01DA , 40DA , 4EDA , 36DA ,
     2    ( PIT)  34D6 , 00D0 , 06D0 , 70D6 , B6D6 , 08D4 , 00D4 ,
     3    ( PPI)  90CE ,  ( PIC)  11C0 , 08C2 , 00C2 , 0FC2 , 00C2 ,
     4    ( FDC)  ( 00EF ,) ( 534 BOARD) 008F , 008C , 928B ,
     5    3683 , 4080 , 0080 , 008D , CE81 , 2781 , 1688 , 0089 ,
     6    168A , 008A , FF89 , FF8B , 008E ,
     7
     8
     9 DECIMAL
    10
    11
    12
    13
    14
    15


568 LIST

     0    ( INITIALIZE I/O)   HEX
     1
     2 ¶ CODE PORTS   0 ,   HERE ' PORTS 2- !
     3    1 POP   0 POP   I PUSH   I 0 XCHG   BEGIN
     4       2 W) IMUL   LODS B   2 0 XCHG   LODS B   (2) OUT   LOOP
     5    STI   I POP   NEXT
     6
     7
     8
     9 DECIMAL
    10
    11
    12
    13
    14
    15


569 LIST

     0 ( SET UP OPERATOR) HEX
     1
     2 ¶ CREATE 'OPERATOR   EA2E ,   PRINTER @ ,   ZERO ,   0 ,
     3    OPERATOR @ 80 - ,   0 ,   0 ,  ' (CR) ,  ' (PAGE) ,  ' (TYPE) ,
     4    D8 ,  D8 ,  ' (EXPECT) ,  THERE  DUP ,  ,  0 ,  0 ,  0A ,
     5
     6
     7 DECIMAL
     8
     9
    10
    11
    12
    13
    14
    15
```

```
570 LIST

    ( POWER UP)   HEX
    ' (NUMBER)   ORIGIN 28 +   ORIGIN 4 -
LABEL START ]   RAM GOLDEN 22 MOVE  IN-LINE ORIGIN 40 MOVE
    INTERRUPTS IN-LINE 14 MOVE
    IN-LINE 'NUMBER !
    'OPERATOR STATUS     DUP 60 ERASE  24 MOVE
    '1AREA    1AREA @    DUP 20 ERASE  0A MOVE
    '2AREA    2AREA @    DUP 20 ERASE  0A MOVE
    '3AREA    3AREA @    DUP 20 ERASE  0A MOVE
    'PRINTER  PRINTER @ DUP 60 ERASE  24 MOVE
    OWN 23 PORTS
    EMPTY PAGE ." up" CR GO  [

DECIMAL
```

```
571 LIST

    ( POWER UP)   HEX

ASSEMBLER   HERE
    0 ES LSG   0 SS LSG   0 DS LSG   START # I MOV
    OPERATOR @   DUP # U MOV   U R MOV   80 - # S MOV
    STD B   NEXT

HERE  ORIGIN 10 - ORG   ZERO # 0 MOV   EA C,  SWAP ,  ZERO ,
ORG       DECIMAL
```

```
572 LIST

( POWERFUL WORDS)

CODE 2-  0 POP 0 DEC 0 DEC 0 PUSH NEXT


CODE INPUT   2 POP   0 0 SUB   (2) IN   0 PUSH   NEXT
CODE OUTPUT   2 POP   0 POP   (2) OUT   NEXT
```

```
573 LIST

( 32-BIT OPERATORS)
FORTH : 2CONSTANT   CONSTANT ,  ;CODE
      4 W) PUSH   2 W) PUSH   NEXT


CODE 0.  0 0 SUB 0 PUSH 0 PUSH NEXT

CODE 2SWAP   2 POP   W POP   0 POP   1 POP
   W PUSH   2 PUSH   1 PUSH   0 PUSH   NEXT
CODE 2OVER   S W MOV   6 W) PUSH   4 W) PUSH   NEXT
```

```
574 LIST

( STATIONARY DATA PRINTING)
: $$ ;
( 426 LOAD 427 LOAD 428 LOAD  )
: CLEAN  0 17 GOTOXY 30 0 DO EL CR LOOP ;
: 1CH  ." CHANNEL"  8 0 DO I 3 SPACES 2 U.R LOOP ;
: 2CH  ." CHANNEL"  16 8 DO I 3 SPACES 2 U.R LOOP ;
: 1DA  ." DATA   " 8 0 DO ANDATA I 2* + @ 5 U.R LOOP ;
: 2DA  ." DATA   " #DP  8 DO ANDATA I 2* + @ 5 U.R LOOP ;
: 1FL  ." FILTER " 8 0 DO FDATA I 2* + @ 5 U.R LOOP ;
: 2FL  ." FILTER " #DP  8 DO FDATA I 2* + @ 5 U.R LOOP ;

: ?DATA  CLEAN 0 17 GOTOXY CR 1CH CR 1DA CR 1FL CR
                          CR 2CH CR 2DA CR 2FL CR ;

: Z ?DATA ;
```

```
575 LIST

( STATIONARY ALARM PRINTING)

: 1CH  ." ALARM  "  10 0 DO I 3 SPACES 2 U.R LOOP ;
: 2CH  ." ALARM  "  20 10 DO I 3 SPACES 2 U.R LOOP ;
: 1AL  ."        " 10 0 DO ALARMS I 2* + @ 5 U.R LOOP ;
: 2AL  ."        " #ALARMS 10 DO ALARMS I 2* + @ 5 U.R LOOP ;

: PALRM  CLEAN 0 17 GOTOXY CR 1CH CR 1AL CR
                          CR 2CH CR 2AL CR  ;

: ZZ PALRM ;
```

```
576 LIST
```

```
577 LIST

( SOFTWARE CLOCK AND TIMER, 800 HZ =  1.@% MS)
TODAY 2+ CONSTANT TICKS
CREATE <CLOCK>  ASSEMBLER  TICKS 2+ INC   0= IF
      TICKS INC   THEN   IRET


CODE COUNTER   TICKS 2+ PUSH   NEXT

: MS   COUNTER  SWAP 8 10 */ +
   BEGIN PAUSE  DUP COUNTER < END  DROP ;
```

```
578 LIST

( TCU-410 CLOCK BOARD  -- CALENDAR)
HEX
A0 CONSTANT TCU410PORT    DECIMAL

: ."  126 WORD C@ DUP HERE 1+ HERE ROT MOVE ALLOT ; IMMEDIATE
CREATE JAN  ." JANFEBMARAPRMAYJUNJULAUGSEPOCTNOVDEC"

: YR  TCU410PORT 5 + INPUT ;
: .YR  1900 + 0 <# # # # # #> TYPE ;
: MTH  TCU410PORT 4 + INPUT ;
: .MTH  1 - 3 * JAN + 3 TYPE ;
: DAY  TCU410PORT 3 + INPUT ;
: .DAY  0 <# #S #> TYPE ;

: DATE  SPACE DAY .DAY SPACE MTH .MTH SPACE YR .YR SPACE ;
```